THE UNIVERSITY OF ALBERTA

# A LIMNOLOGICAL SURVEY OF A ROCKY MOUNTAIN COLD SPRING WITH COMMENTS ON A POSSIBLE GLACIAL REFUGIUM

by

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(C)

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance a thesis entitled

A LIMNOLOGICAL SURVEY OF A ROCKY MOUNTAIN COLD SPRING WITH COMMENTS ON A POSSIBLE GLACIAL REFUGIUM

submitted by Glen P. Bergstrom

in partial fulfillment of the requirements for the degree of Master of Science

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Supervisor

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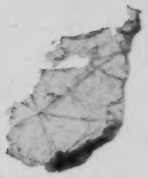
Date 9 October

ABSTRACT

Cadomin Spring is a cold mountain spring located on the eastern slopes of the Canadian Rockies near Cadomin, Alberta, about 300 km south west of Edmonton. Streamflow responds rapidly to surface water runoff, either from snow-melt or summer storms. Water temperature, which fluctuates inversely to streamflow, varies between $4^{o}C$ - $7^{o}C$, the highest temperature occurring during fall and winter months when primarily baseflow contributes to the spring flow. Because the baseflow temperature ($7^{o}C$) is not equal to the mean annual air temperature ($-0.1^{o}C$) it is probable that the baseflow is from a deep water source. In contrast dissolved oxygen concentrations vary directly with streamflow, with maximum values (8 mg/1) during maximum runoff periods in spring and summer and undetectable levels during low flow in fall and winter. The other measured chemical constituents generally indicated good water quality, although periodically during winter months, when dissolved oxygen concentrations were very low, significant growths of the sulfur reducing bacteria, *Beggiatoa alba* were noted.

The Cadomin Spring fauna was generally indicative of an impoverished community, the dominate taxa being a few Chironomidae and Oligochaeta. The only insects that completed their life cycle in Cadomin Spring were chironomids and the trichopteran *Ecclisomyia*. The ephemeropteran *Ameletus* migrated up from the McLeod River in the spring months when dissolved oxygen concentrations increased. The *Ameletus* population was able to emerge



successfully from the Spring during July and August. The only other successful group was the harpactacoid *Attheyella nordenskioldii* (Copepoda), which was able to survive and reproduce year-round. The flatworm *Polycelis coronata* did not appear to be able to reproduce sexually although asexual budding was noted on a number of occasions.

A possible relict aquatic hypogean isopod *Salmasellus steganothrix* was found in the Spring. This finding and the presence of the oligochaete *Rhynchelmis etrodi* are discussed in respect to Cadomin Spring being a possible refugium during the Wisconsin glaciation.

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In particular I am grateful to my government colleague Paul Jablonski for invaluable field assistance throughout the study.

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# INTRODUCTION

In recent years, springs have received much attention from aquatic biologists (Odum 1957). The reasons are probably threefold. Firstly, the constant physical and chemical environment of Springs, relative to lakes and rivers, have presented the researcher, often plagued with the uncertainty of extrapolating artificial laboratory results to the field situation, with a natural outdoor laboratory. Secondly, the reduction in the fauna of most Spring communities provides a simplified system allowing in-depth studies of community interactions (Noel 1954, Minckley 1963, Minshall 1968, Marshall 1973) and metabolism (Odum 1957, Teal 1957). Thirdly, the constant conditions of springs can allow relict animals to survive in climates that show considerable variation.

In 1974, a blind hypogean isopod was collected from a cave-spring on the eastern slopes of the Rocky Mountains. This represented an extraordinary extension of the North American hypogean isopods (Clifford and Bergstrom 1976). It was felt that the Spring might support other relict animals, and, even if it did not, a limnological study of this unique system, e.g. a subarctic flowing water system that remains ice-free in winter, should be profitable. Therefore, in the summer of 1975, a detailed investigation of the Spring commenced and continued until September 1976.

The specific objectives of the study can be outlined

as follows: 1) to establish baseline physical and chemical parameters; 2) to evaluate qualitatively the fauna in regards to seasonal distributions, relative abundances and, where possible, life histories: and 3) to consider the possibility of Cadomin Spring as a refugium during Wisconsin glaciation.

In the broader sense, I hoped that the present study would stimulate much needed interest in the study of springs in Western Canada. I know of no other limnological studies, carried out on a yearly basis, of northern springs.

# DESCRIPTION OF THE STUDY AREA

## Study Site

Cadomin Spring, 300 km west-southwest of Edmonton, Alberta, and about 3.3 km south of the hamlet of Cadomin, is located along the eastern slopes of the Rocky Mountains' Nikanassin Range, ($53^{o}$ 02' N, $117^{o}$ 20' W at 1525 m asl). (Fig. 1). The Spring flows into the McLeod River, a tributary of the Athabasca River of the Arctic Ocean drainage. Eight km south of the Spring is the divide separating the north-flowing headwaters of the McLeod River from the east-flowing Cardinal River of the North Saskatchewan River, a drainage that enters Hudson Bay.

The cave-spring's orifice, located at the base of a mountain, was too small to permit access (Plate 1). Thus, the size and extent of the cave system could not be determined.

The main surface channel, about 50 meters long, consisted of three riffles and two pools (Fig. 1). Riffle #1 (Plate 2), immediately adjacent to the orifice, was 3 to 4 meters wide and was both the deepest and swiftest of the three riffles. Riffles #2 and #3 (Plates 3 and 4) were 4 and 6 meters across, respectively, with riffle #3 about one-fourth to one-half the depth of riffle #2. Using the substrate classification system of Lane *et al* (*in* Guy 1969), I determined that all three riffles contained mainly large cobble (128-256 mm in diameter) with some boulders (as large as 7256 mm in diameter). The largest number of boulders occurred in midchannel of riffle #1.

A minor channel, paralleling the road, flowed out of the

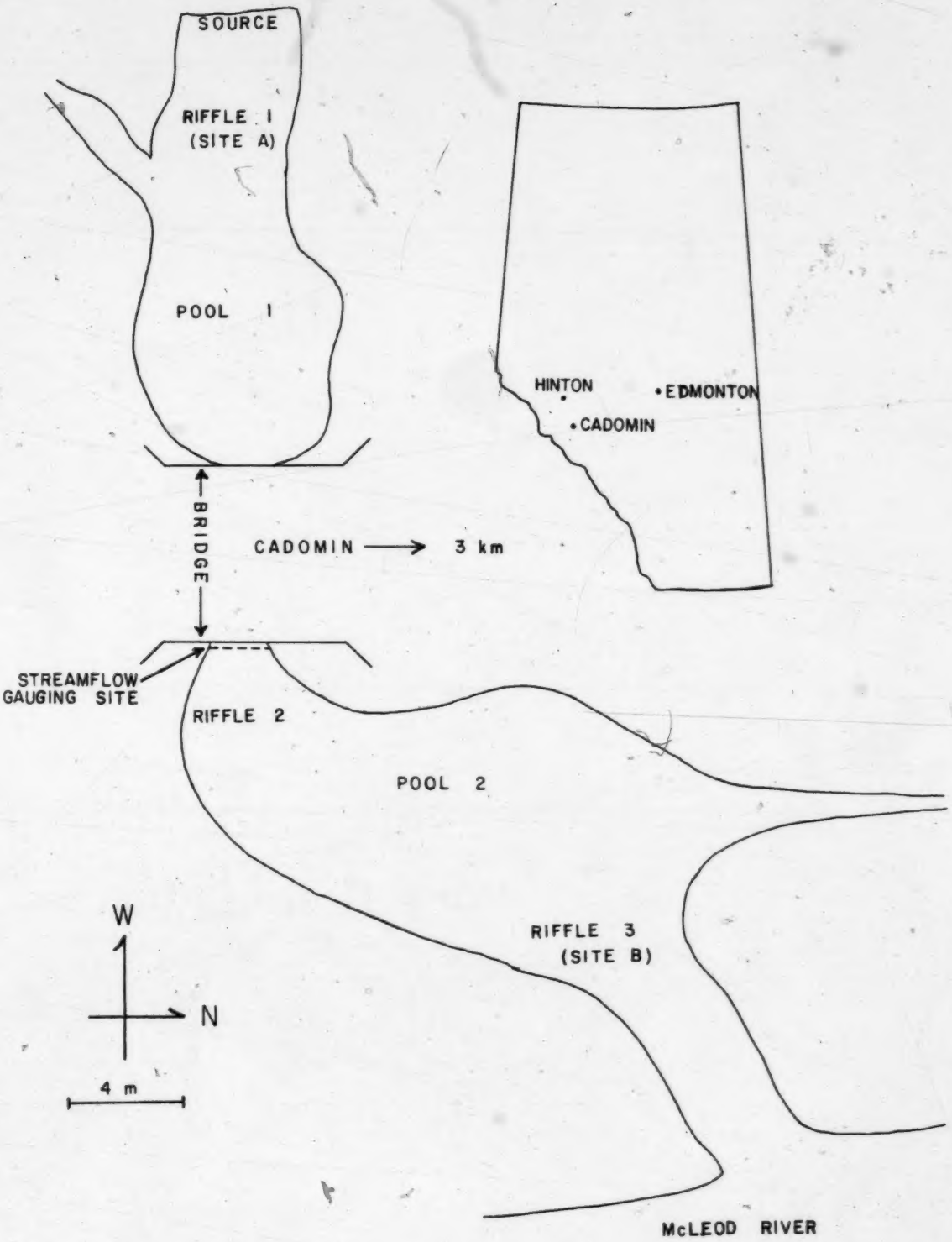



Figure 1 Map of study area.

Plate 1. The Spring orifice

Plate 2. Riffle #1

Plate 3. Riffle #2

Plate 4. Riffle #3

Plate 5. Fault directly east of Cadomin Spring - - - -

Plate 6. Growth of *Beggiatoa alba*

north-west corner of pool #2. Although it acted primarily as a spillway during high water, it flowed during the entire year. Its substrate was generally much smaller than that observed in the main channel.

## Bedrock Geology

The Rocky Mountain front range is composed of carbonates, shales, and sandstones of Devonian to Permian age (Mountjoy 1962). The Palliser Formation of Upper Devonian age and the overlying beds of Carboniferous age comprise the Nikanassin Range (Gotts 1966), from which Cadomin Spring flows. Rich deposits of Devonian limestone accounted for Inland Cement Industries Ltd., Edmonton, Alberta, establishing a quarry in Cadomin in 1956. The limestone has been faulted over Jurassic and Cretaceous shales and sandstones of the Fernie and Nikanassin Formations by the Nikanassin thrust (Gotts 1966). Fossils are scarce in these limestone deposits, although they have been collected in the Jurassic shales a few centimeters below the thrust. About 0.8 km south of the quarry, directly east of Cadomin, the Devonian limestone is exposed by another fault, but here the Palliser Formation overlies Mississippian limestone of the Rundle group (Plate 5). I was not able to determine whether this fault accounts for the location of Cadomin Spring, although it is not unreasonable to suggest this.

## Climate

The Atlas of Canada (1957) classifies the Cadomin area as humid, microthermal and subarctic. The Koppen classification indicates a rain-snow climate of cold winters, short and cool summers (only 1 to 3 months with mean temperatures above 10°C) and precipitation throughout the year. Air temperature readings were obtained from a hydrothermograph located 16 km north of Cadomin Spring in the Tri-Creeks Watershed Study Area. In 1975, only July had a mean air temperature above 10°C (13.5°C), while in 1976 only August exceeded 10°C (10.8°C) (Fig. 2). The mean annual air temperature for 1967-1977 was -0.7°C at the Wampus A station (1280 m asl), where frost can occur during all months of the year.

Precipitation storage gauges, serviced throughout the year, in the Tri-Creeks Watershed Study provided monthly precipitation values. In 1974-1975, total precipitation was 52.6 cm, 60% falling between 1 May - 31 October. In 1975-1976, total precipitation was 70.4 cm, 69% falling between 12 May - 14 October (Jablonski 1978). Between 1967 and 1977, mean annual precipitation was 68.8 cm with 62% falling between 1 May and 31 October (Fig. 3).

Strong winds commonly occur in the Cadomin area, especially November-January. During the winter months, chinooks are not infrequent, and within a few hours they can raise temperatures well above freezing.

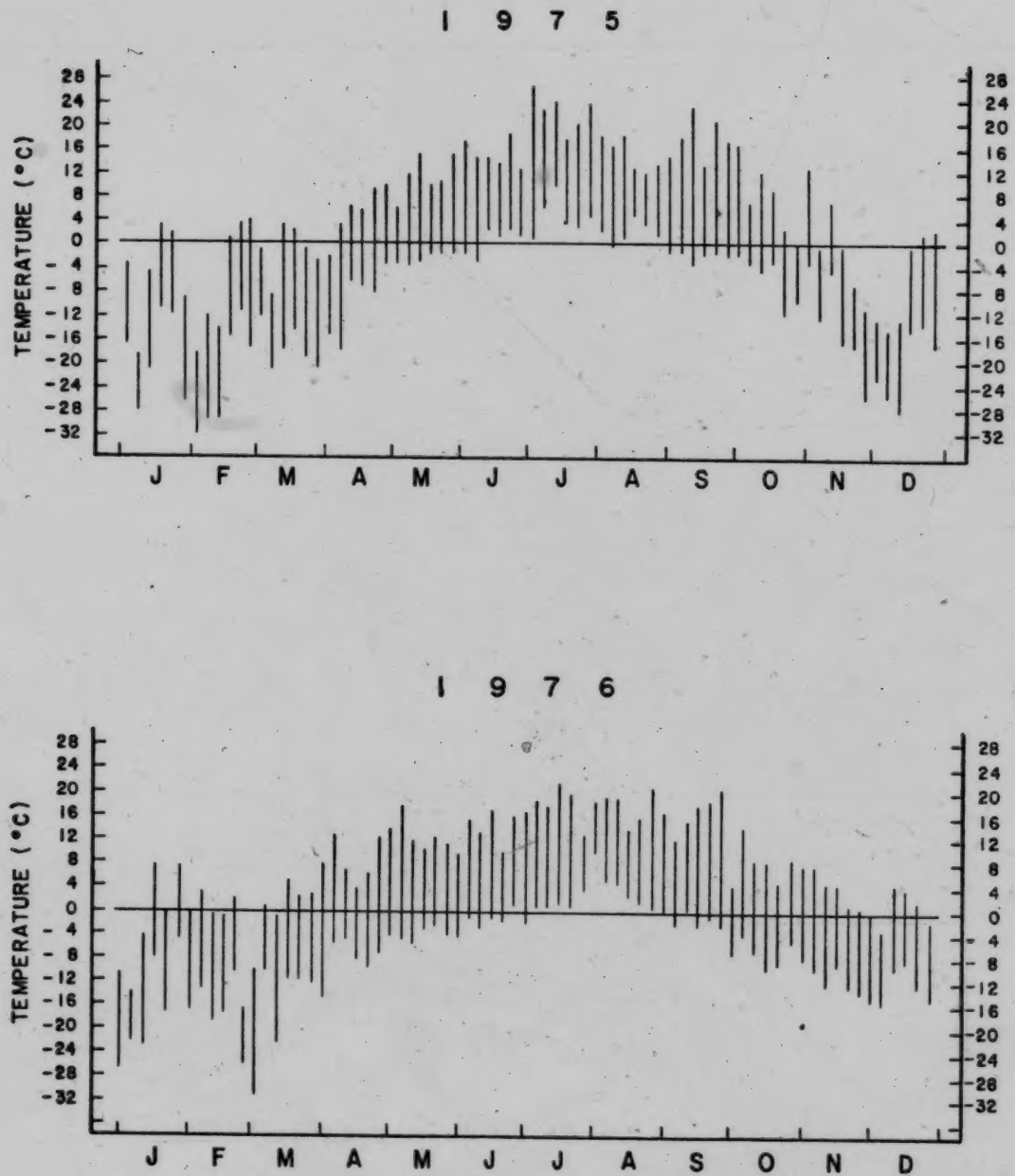



Figure 2. Mean five day maximum and minimum air temperature readings from Tri-Creeks Watershed Study, 10 km north of Cadomin Spring.

## Natural History

The elevation, latitude and climate of the Cadomin area and its proximity to the foothills and the lower mountain slopes defines the flora and fauna as typical of the Canadian Zone. A few kilometers south of Cadomin, the Canadian Zone merges into the Hudson-Canadian (Sub-alpine) Zone, the upper limits being the timberline (Williams 1966).

### Flora

The forest of this well-drained upland area is dominated by coniferous stands of lodgepole pine (*Pinus contorta*) with some white spruce (*Picea glauca*) and black spruce (*Picea mariana*). Hardwoods such as poplar (*Populus* spp.) and birch (*Betula* spp.) are relatively uncommon and local. Dominant flowers and plants comprising the understory and open meadows are Labrador tea (*Ledum groenlandieum*), wild raspberry (*Rubus strigosus*), wild rose (*Rosa acicularis*), bearberry (*Arctostaphlos* spp.), twin flower (*Linnaea borealis*), bunchberry (*Cornus canadensis*), wintergreen (*Pyrola* spp.), fire weed (*Epilobium* spp.), Indian paintbrush (*Castilleja* spp.), and various junipers (*Juniperus* spp.) and mosses. Ascending into the sub-alpine forest, which Rowe (1959) describes as the Boreal Forest, Engelmann spruce (*Picea engelmanni*) with alpine fir (*Abies lasiocarpa*) and lodgepole pine are dominant. The understory remains similar to the Canadian Zone.

### Vertebrate Fauna

Soper (1964) suggests that at least 51 species of mammals occur in the Cadomin area, ranging from the pygmy shrew to the

grizzly bear. World trophy elk and bighorn mountain sheep have been taken. Records indicate that mountain goat and bighorn sheep were plentiful prior to mining activity. Excessive hunting apparently drastically reduced the sheep and goat populations. Due to more stringent hunting regulations, the bighorn sheep population has increased, but the mountain goat has never recovered. A reduction in fisher and martin populations is now expected because of habitat loss from increased logging activity. An anti-rabies campaign from 1952-1956 apparently reduced some mammal populations, particularly the bears, cougars, coyotes and wolves. Fortunately, most of these populations are now increasing in numbers.

About 136 species of birds are believed to nest in the area, with many more passing through on migratory routes. Raptors such as hawks and the golden eagle are frequently seen. Six species of owls including the rare great grey owl have been recorded from the area. The nasal call of the nighthawk as it flies about in the late evening is a familiar sound to the area. Waterfowl and shore birds are not abundant, but one duck that does inhabit the area is the colorful harlequin, its habitat being cold mountain streams. The sandpiper is the common shorebird. The rare pileated woodpecker is not uncommon in this area. For a complete species list see Salt and Salt (1976).

The common game fish in area streams are rainbow trout (*Salmo gairdneri*), Dolly Varden (*Salvelinus malmo*), and mountain whitefish (*Prosopium williamsoni*). Fish, especially rainbow trout, have been stocked in some abandoned pits filled with water. Eastern brook

trout (*Salvelinus fontinalis*) have also been introduced and proven successful. There are no fish in Cadomin Spring per se.

## Historical Background

During the early 1900's, many coal mining communities were established in central Alberta. At the peak of coal production, about 16,500 people lived in these communities (Dumanski *et al* 1972). By the late 1940's diesel powered locomotives began replacing steam locomotives, and the demand for coal dwindled. The mines began closing and by the early 1950's most of the communities had become ghost towns.

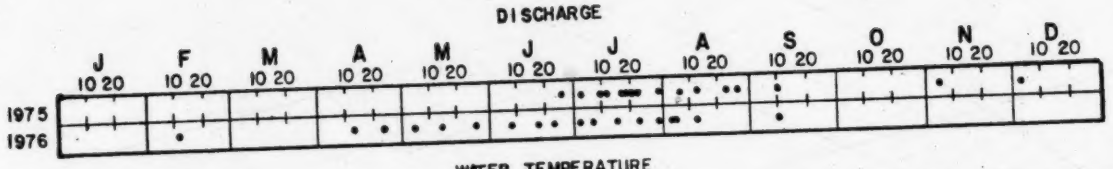
One of the few communities to survive was Cadomin. After coal mining operations were terminated in 1952, Inland Cement Company became interested in the rich deposits of limestone found in Cadomin Mountain. A quarry, employing about 25 people, was established in 1956. The life expectancy of the quarry is between 1990 and 1995.

With impending shortages of gas and oil, coal reserves in the abandoned mines are once again being considered. Vast coal deposits in the area still remain unexploited. Some mines have already been re-opened to strip-mining. However, the colorful, almost romantic community life is gone forever. Re-establishment of old abandoned communities or establishment of new communities at mining sites is now forbidden by the Government. Companies must commute their employees from larger centers, mainly Edson and Hinton, to the mining sites.

Figure 3. Sampling regime for physical, chemical and biological parameters. Dots indicate sampling times.

## PHYSICAL

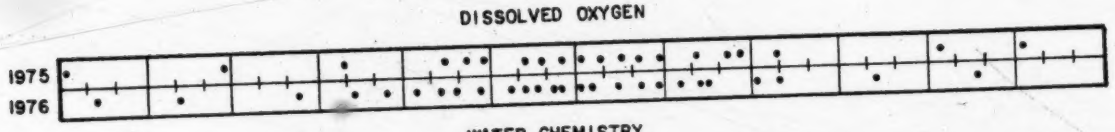
DISCHARGE



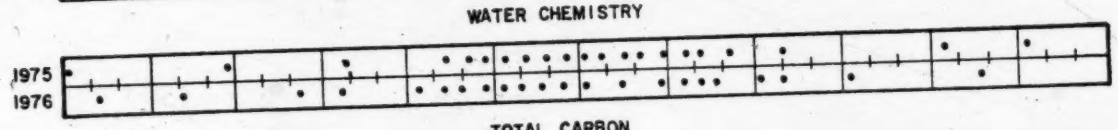

WATER TEMPERATURE

## CHEMICAL

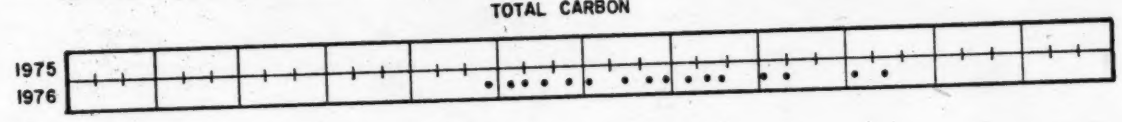
DISSOLVED OXYGEN




WATER CHEMISTRY

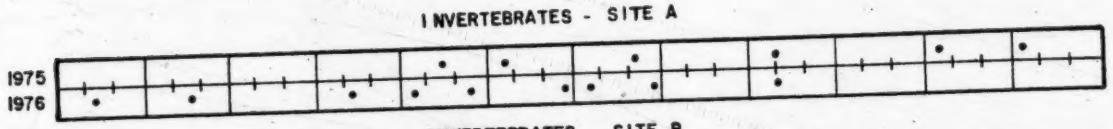



TOTAL CARBON

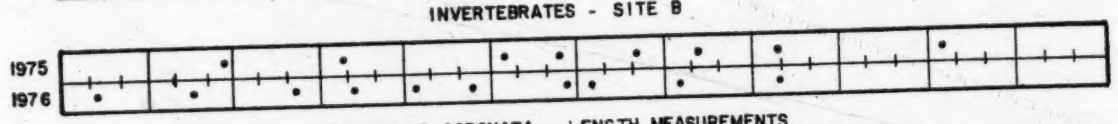



## BIOLOGICAL

INVERTEBRATES - SITE A

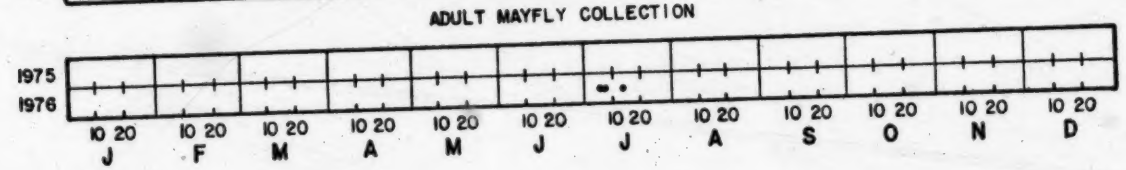



INVERTEBRATES - SITE B




POLYCELIS CORONATA - LENGTH MEASUREMENTS

ADULT MAYFLY COLLECTION



# METHODS AND MATERIALS

## Physical

From 15 May 1975 through 10 September 1976, a metering station was set up immediately below the bridge (Fig. 1), where streamflow was monitored weekly throughout spring and summer, and monthly, when possible, during fall and winter (Fig. 3). All measurements were taken with a Gurly velocity current meter. Stream depth was read from a staff gauge attached to the outside bridge pier. Linear regression analysis was used to compute a rating curve defining the relationship between discharge measurements (the independent variable) and the corresponding stream depth readings (dependent variable). By developing this curve, discharge readings did not have to be taken during every visit.

Water temperature readings were taken during each visit using a hand thermometer. A maximum-minimum thermometer was installed on 14 April 1976. However, the only reasonably safe place for installation was among some large rocks near the source, but the turbulence at this location disengaged the thermometer's barbells. Hence I was not able to obtain continuous maximum-minimum readings.

## Chemical

Water samples were collected weekly throughout spring and summer and every 1 to 2 months during fall and winter. Samples were collected at the source in polyethylene bottles and returned to the Department of Zoology water laboratory at the University of Alberta for analysis. During 1975, samples were frozen before analysis;

however, in 1976 samples were only refrigerated and analyzed within 7 days of collection. In 1976, a number of samples were also collected for total organic and inorganic carbon analysis.

In 1975, samples for dissolved oxygen samples were collected only at the source. During 1976, dissolved oxygen samples were taken from below riffle #2 and site B to determine the amount of aeration taking place between sites A and B. All samples collected from A were measured using the conventional Winkler's method, while dissolved oxygen below riffle #2 and site B was measured with a YSI dissolved oxygen meter calibrated to the samples taken at site A.

## Biological

Sampling commenced at site B on 27 February 1975 and at site A on 6 June 1975. Samples were collected every 3 weeks to 1 month during spring and summer and every 1 or 2 months during winter. Throughout the study period, it was not always possible to sample sites A and B on the same dates, especially during winter (Fig. 3).

Only qualitative samples were collected, using a long-handled dipnet with a mesh size of 420 microns. The sampling technique was similar to that described by Hynes (1961). The dipnet was held on the stream bottom and the area immediately upstream of the net disturbed by foot, causing organisms to be dislodged and carried by the current into the net. Spot sampling from different points over the riffle comprised one sample. Ten percent formalin was used to preserve the sample. One week after collecting the sample the old preservative was poured off and fresh 4% formalin added. The sample

was then stored until analysis.

During spring of 1976, the migratory behavior of the mayfly *Ameletus* was monitored as the nymphs moved from the McLeod River into Cadomin Spring. Later, in early summer, emerging adults were collected. They could be positively identified as emerging from Cadomin Spring because of their cast nymphal skins, which were found attached to rocks of the Spring at the water surface. The subimagoes were returned to the laboratory and allowed to transform into imagoes before being preserved in 95% ethyl alcohol.

An emergence trap was installed 19 May 1976 to collect adult chironomids for species identification and assist in determining life histories. Adults were collected on 26 and 28 May, but by 1 June the trap was gone. I attempted to put a second trap in on 7 September, but this became the target of some hunters. Vegetation sweeps were not attempted because the close proximity of the McLeod River made it impossible to identify the source of the chironomids.

I studied growth in the flatworm *Polycelis coronata* in 1976. Live specimens were collected periodically throughout summer and fall (Fig. 3): total length was measured following the technique described by Folsom (1976). The flatworms were placed in a clear petri dish containing water from Cadomin Spring. The dish was then put on graph paper containing 1 mm lines and the worms measured to the nearest millimeter as they glided along the bottom of the dish. The worms were then returned to Cadomin Spring.

Picking and sorting the preserved samples was done using a Wild M3 stereomicroscope at 6.4 power. Initially all organisms

were removed, but this proved to be too time-consuming. To reduce the picking time, I used a subsampler, which consisted of a 128 ml jar with the bottom divided into eight equal parts by metal separators embedded in paraffin wax. Alcohol, because of its low specific gravity, was the sampler's liquid medium. A sample, with its preservative removed, was placed in the jar, mixed well and allowed to settle. One-half the sample was then removed for analysis by suctioning alternate sections into a vacuum flask. Tests done on the efficiency of this subsampling procedure (Appendix 1) indicated that it was at least 95% accurate in predicting total counts of the major taxa.

General taxonomic keys of Pennak (1953), Ward and Whipple (1959), and Usinger (1963) along with specific keys for mayflies (Needham *et al* 1935) and for oligochaetes (Brinkhurst and Jamieson 1971) were used to identify all taxa except the chironomids and the hypogean isopod. Chironomids were identified by Dr. D. A. Oliver, Biosystematic Research Institute, Ottawa, Ontario, and the isopod was identified by Bowman (1974) as a new genus.

Approximately 100 chironomid larvae were chosen randomly from each sample. One hundred specimens were suggested to be sufficient by both Dr. H. Boerger, University of Calgary, and Dr. D. A. Oliver, Ottawa (per comm.). The chironomids were divided into groups and representatives from each group sent to Dr. D. A. Oliver in Ottawa for identification. Based on these identifications, a percent composition matrix was constructed, representing each member from each sampling date (Appendices 8 & 9).

Once all identification and numerical computations were completed, biomass was determined by drying the invertebrates at $90^{o}C$ for 12 hours and weighing.

## RESULTS AND DISCUSSION

### Physical Characteristics

#### Streamflow

A rating curve correlating gauge height with discharge is shown in Figure 4. The mathematical model providing the best fit was $Y = a + b\sqrt{X}$, where Y = gauge height, X = discharge, a = intercept and b = slope. The high correlation coefficient, r = 0.99, and the small standard error, $s_{yx} = 0.016$, indicate most of the variation is accounted for in the regression. Thus, given a gauge height, I was able to predict accurately the discharge.

Cadomin Spring was characterized by rapid hydrologic responses to snowmelt and summer storms (Fig. 5), indicating a network of cracks or fissures draining surface water directly into the cave spring cavern or into channels communicating with it. Maximum discharge due to summer storms was 1.20 cms (5 August 1976) while maximum discharge recorded during the snow-melt period was 0.38 cms (5 May 1976). Lack of precipitation in 1975 caused low flows during most of summer while in 1976, major storms throughout the summer kept output high (Fig. 5). Mean flow from 25 June to 30 September 1975 was 0.25 ± 0.19 cms (based on 15 measurements) while in 1976 it was 0.42 ± 0.33 cms (based on 11 measurements) for the same period.

Flow throughout fall and winter of 1975-1976 was characterized

by a slow, consistent decline; this was due to no surface water being available and the deeper ground water supply being depleted.

Water Temperature

Contrary to the typical water temperature in northern surface streams, the water temperature profile of Cadomin Spring indicates that temperatures were maximum (8.0°C, 5 November 1975) in winter and minimum (1.5°C, 2 July 1975) in summer (Fig. 6). Mean winter temperature was essentially constant at 7.1°C ± 0.5°C (7 measurements). Mean summer water temperatures for 1975 and 1976 were 5.9 ± 1.0°C (18 measurements), respectively.

My data do not agree with the accepted view regarding ground-water temperatures, i.e. being equivalent to the mean annual air temperature of the region (Hynes 1970). The mean annual air temperature for the Cadomin area is only -0.7°C (Jablonski 1978). The Cadomin Spring had a much higher average water temperature.

Turbidity

The Federal Water Pollution Control Administration (1968, p. 46) defines turbidity as "an expression of the optical property of a sample of water which caused light to be scattered and absorbed rather than transmitted in straight lines through the sample." Turbidity levels were generally very low, indicating very clear water, usually below 2 Jackson Turbidity Units (JTU) (Fig. 6b). Even during snow-melt and summer storms of 1976, turbidity remained essentially constant. The higher, more variable 1975 readings probably resulted from samples being frozen before analysis, one explanation being that when samples are frozen $CO_2$ is driven off;

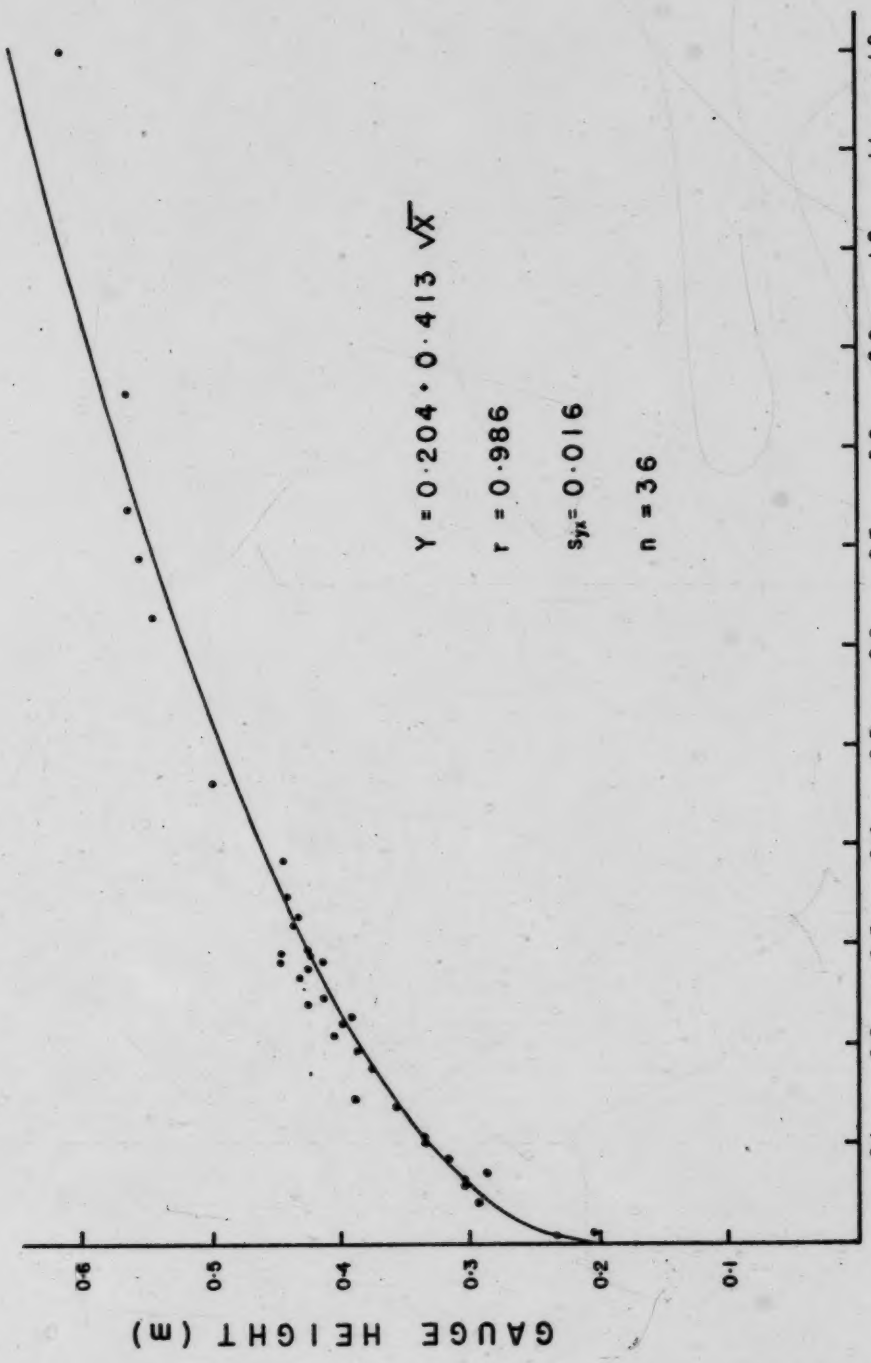



Figure 4. Rating curve demonstrating the relationship between streamflow and gauge height. Y = Gauge Height, X = Discharge, r = correlation coefficient, $s_{yx}$ = standard error, and n = number of readings taken.

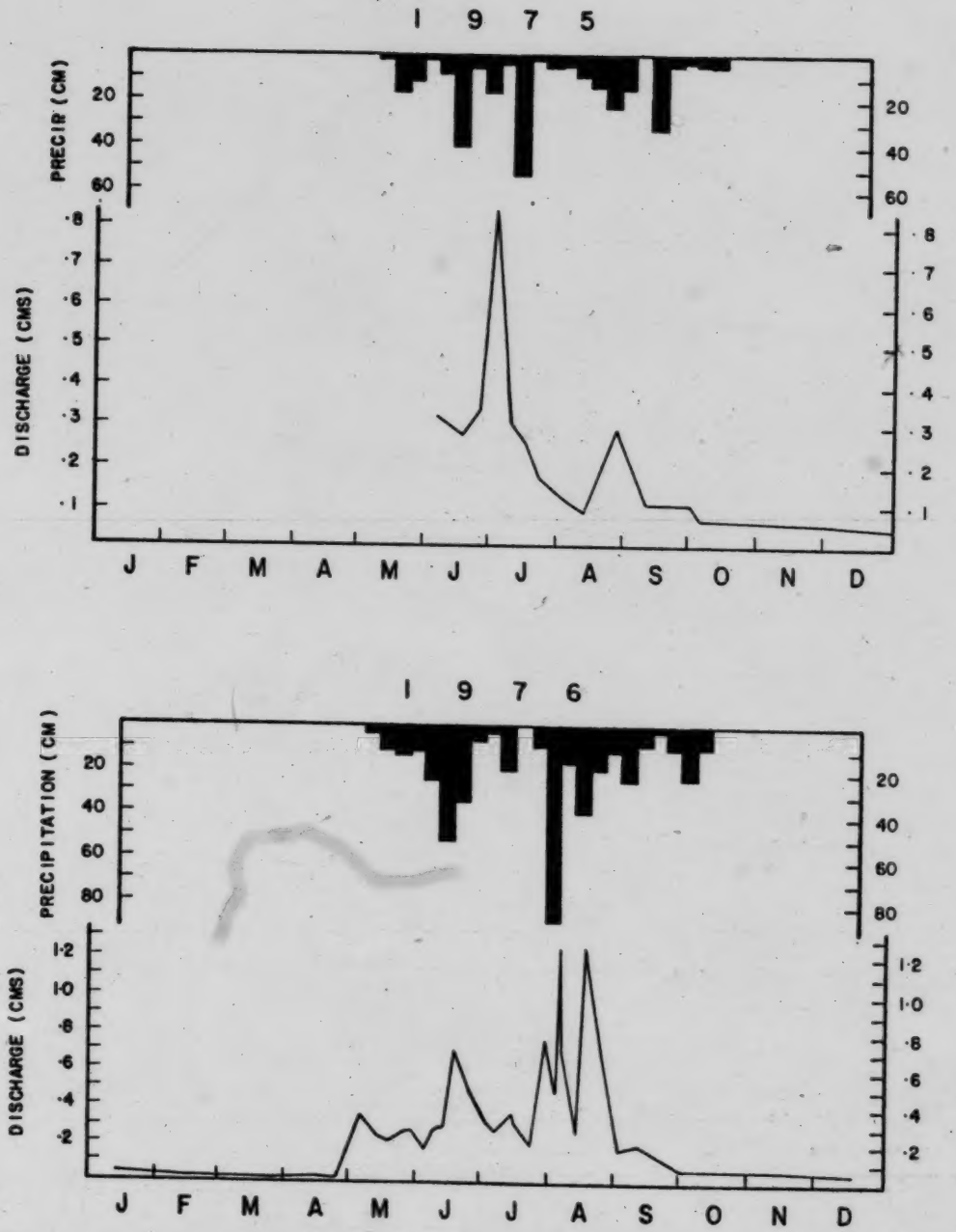



Figure 5 . Streamflow readings from 1975 and 1976. Precipitation records from Tri-Creeks Watershed Study, 10 km north of Cadomin Spring. Each precipitation bar represents one week's accumulation.

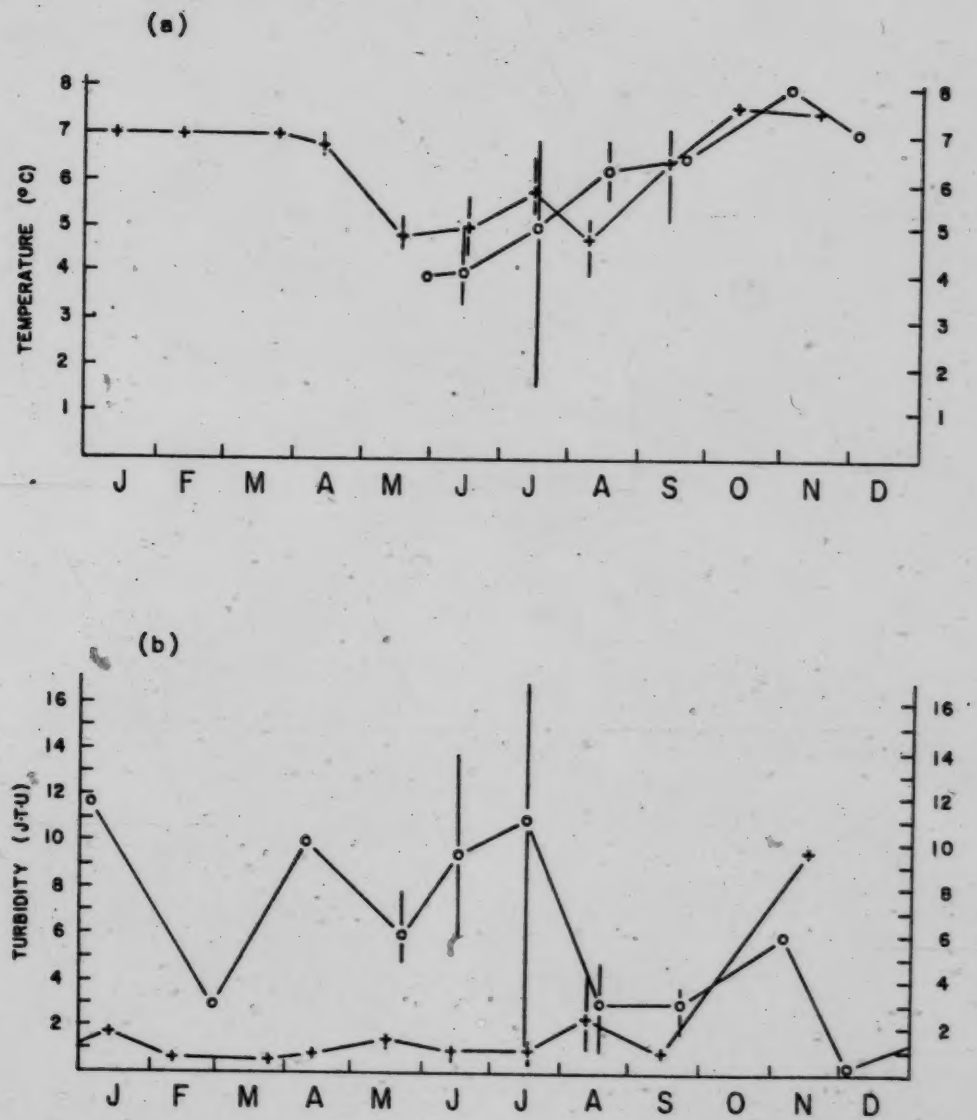



Figure 6 Mean monthly readings for water temperature (a) and turbidity (b). Vertical lines represent ranges. o = 1975 data, + = 1976 data.

Table 1 Proportions of $CO_2$, $HCO_3^-$, and $CO_3^=$ in water at various pH values.[a]

| pH | Total Free $CO_2$ | $HCO_3^-$ | $CO_3^=$ |
|---|---|---|---|
| 4 | 0.996 | 0.004 | $1.25\ 10^{-9}$ |
| 5 | 0.962 | 0.038 | $1.20\ 10^{-7}$ |
| 6 | 0.725 | 0.275 | $0.91\ 10^{-5}$ |
| 7 | 0.208 | 0.792 | $2.60\ 10^{-4}$ |
| 8 | 0.025 | 0.972 | $3.20\ 10^{-3}$ |
| 9 | 0.003 | 0.966 | 0.031 |
| 10 | 0.0002 | 0.757 | 0.243 |

[a] From Hutchinson, G.E.: A Treatise on Limnology. New York, John Wiley & Sons, Inc. 1957, p. 657.

and then, when the sample is at about room temperature, $HCO_3^-$ dissociates to yield a $CaCO_3$ precipitate, and this increased turbidity. The insignificant increases in turbidity during high flows would indicate that the surface water entering the cavespring cavern is derived primarily from rocky slopes.

## Chemical Characteristics

### Hydrogen Ion, Alkalinity, Hardness

The pH ranged from 7.1 to 8.3 in 1975 and 7.2 to 7.8 in 1976 (Fig. 7a). There was no apparent relationship between pH and discharge. Seasonal alkalinity patterns over the 2 years were similar, although 1976 concentrations (90-122 ppm) were higher and more consistent than in 1975 (55-120 ppm) (Fig. 7b). Alkalinity was inversely related to discharge with high concentrations in the winter and lower concentrations during spring and summer. Table 1 shows the relationship between pH and alkalinity in determining which component of alkalinity (carbonates, bicarbonates or hydroxides) is predominant. Cadomin Spring pH values (7.1-8.3) would indicate the bicarbonate ion as predominant.

Total hardness varied inversely with streamflow, concentrations ranging from 98 ppm in the spring and summer to 280 ppm in the winter (Fig. 8a). Water with total hardness below 60 ppm is considered soft and above 180 ppm hard; thus, Cadomin Spring would have medium (spring and summer) to hard (winter) water. The difference between calcium and total hardness concentrations gives the approximate magnesium concentration.

Frequently throughout the year magnesium concentrations

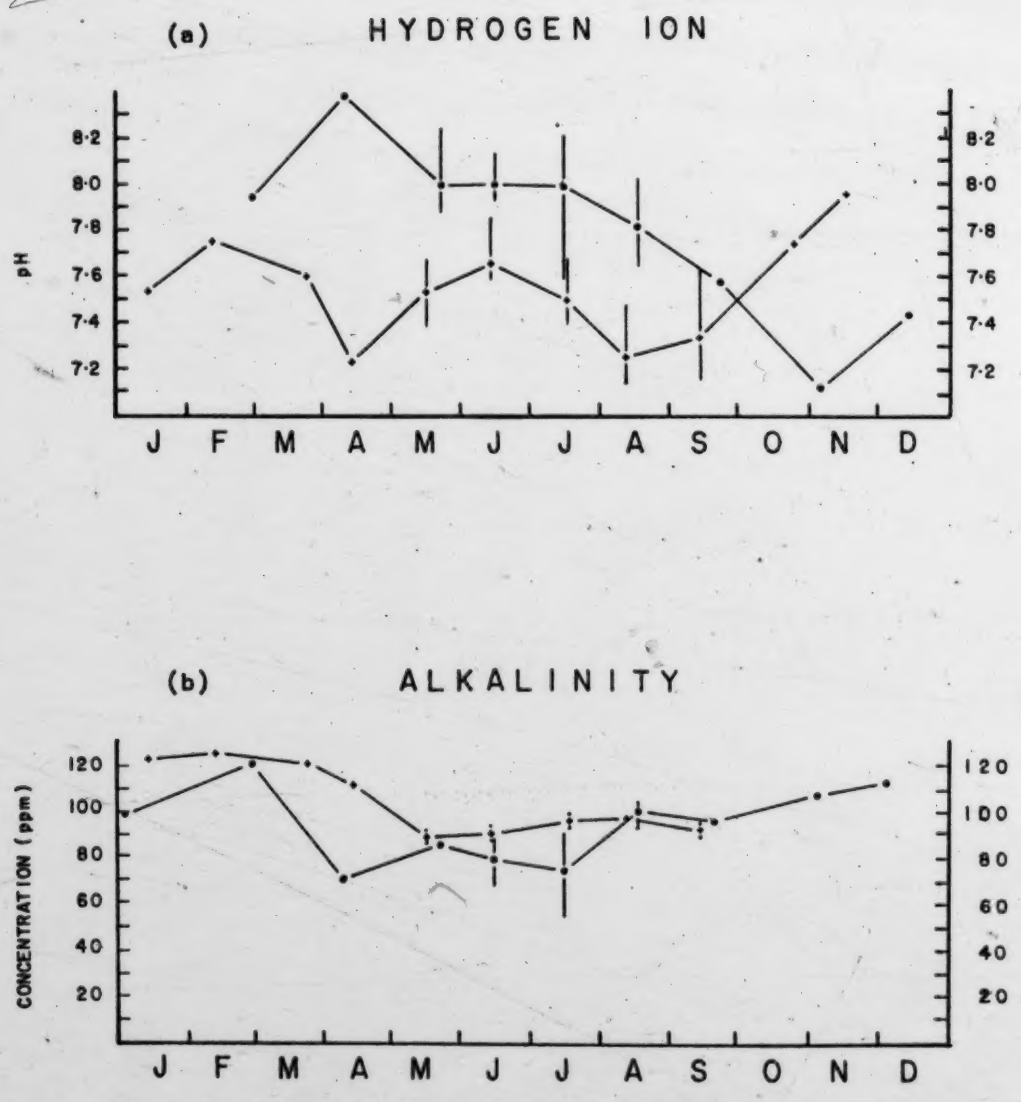



Figure 7 Mean monthly readings for pH (a) and alkalinity (b). Vertical lines represent ranges. o = 1975 data, + = 1976 data.

were nearly equal to calcium, suggesting extensive contact of the spring water with dolomite rock beds (Hem 1970).

Specific Conductance and Total Residue

Specific conductance is an electrical measurement of the total ionic concentration of water. Total residue, on the other hand, is a weight measurement of dissolved solids and is determined by evaporating a known amount of water and weighing the residue. However, caution should be exercised as total residue often includes unfiltered material in suspension as well as total dissolved solids, while conductivity only measures the dissolved ionic content.

Conductivity readings ranged from 75-430 micromhos in 1975 and 185-388 micromhos in 1976 (Fig. 9a). Readings were inversely proportional to streamflow, with maximum values occurring just prior to the snow-melt period. The regime was similar in both years although variations during 1975 were greater than in 1976. Total residue results followed a similar pattern to specific conductance, except that total residue ranges about the monthly means were substantially greater (Fig. 9b).

Sulfate

Primary sources of sulphate are: 1) weathering of metallic sulfides in sedimentary rock in contact with water, 2) pyrite ($FeS_2$) usually associated with coal deposits, and 3) decomposition of organic matter $H_2S$, which under oxic conditions is converted to sulfate. Coal deposits are present in the Cadomin area: however, Berkowitz (1969) stated that western Canadian bituminous coal generally contained only 0.2% - 0.3% pyritic sulfur. Thus, sulfate

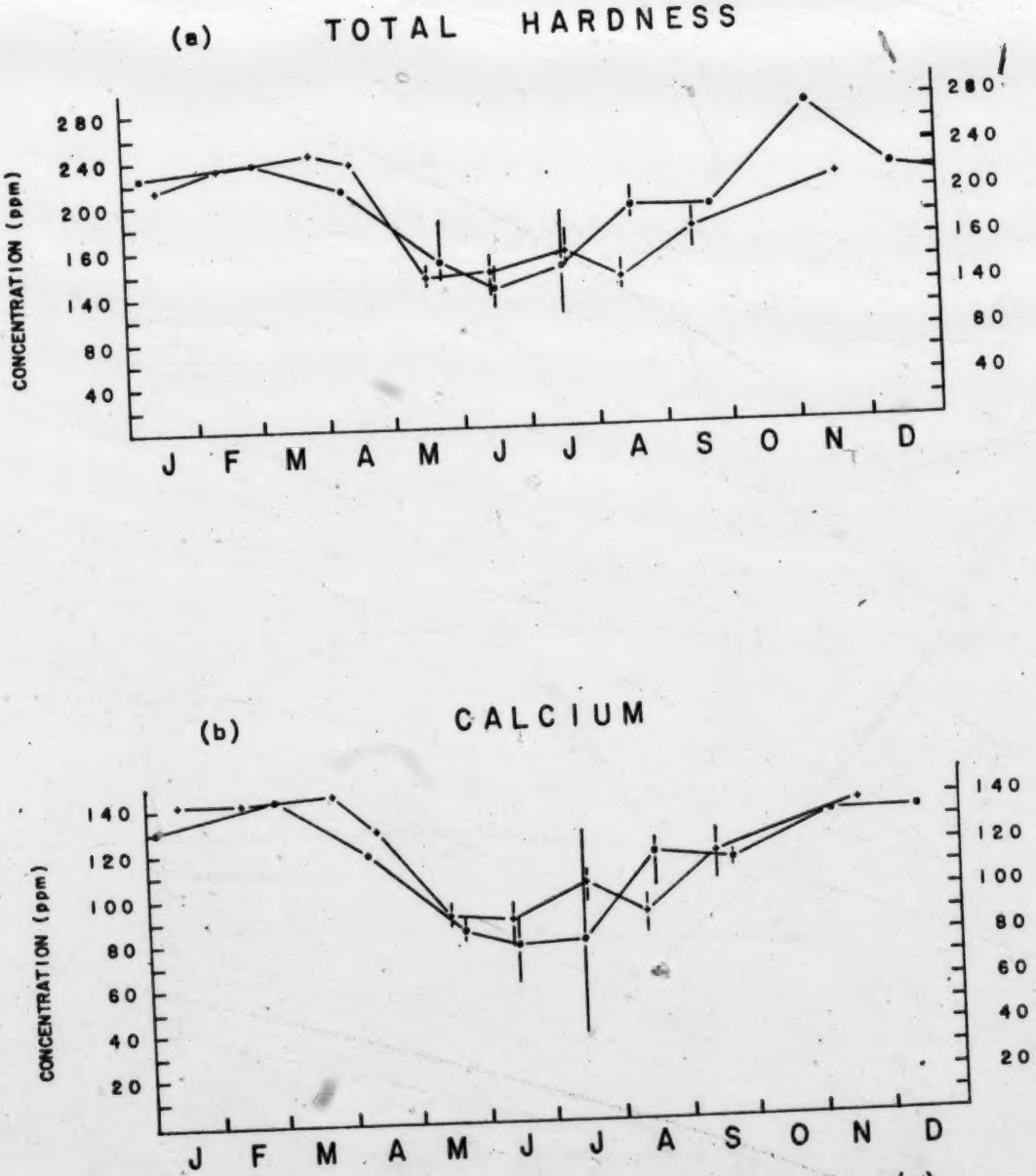



Figure 8 Mean monthly readings for total hardness (a) and calcium (b). Vertical lines represent ranges. o = 1975 data, + = 1976 data.

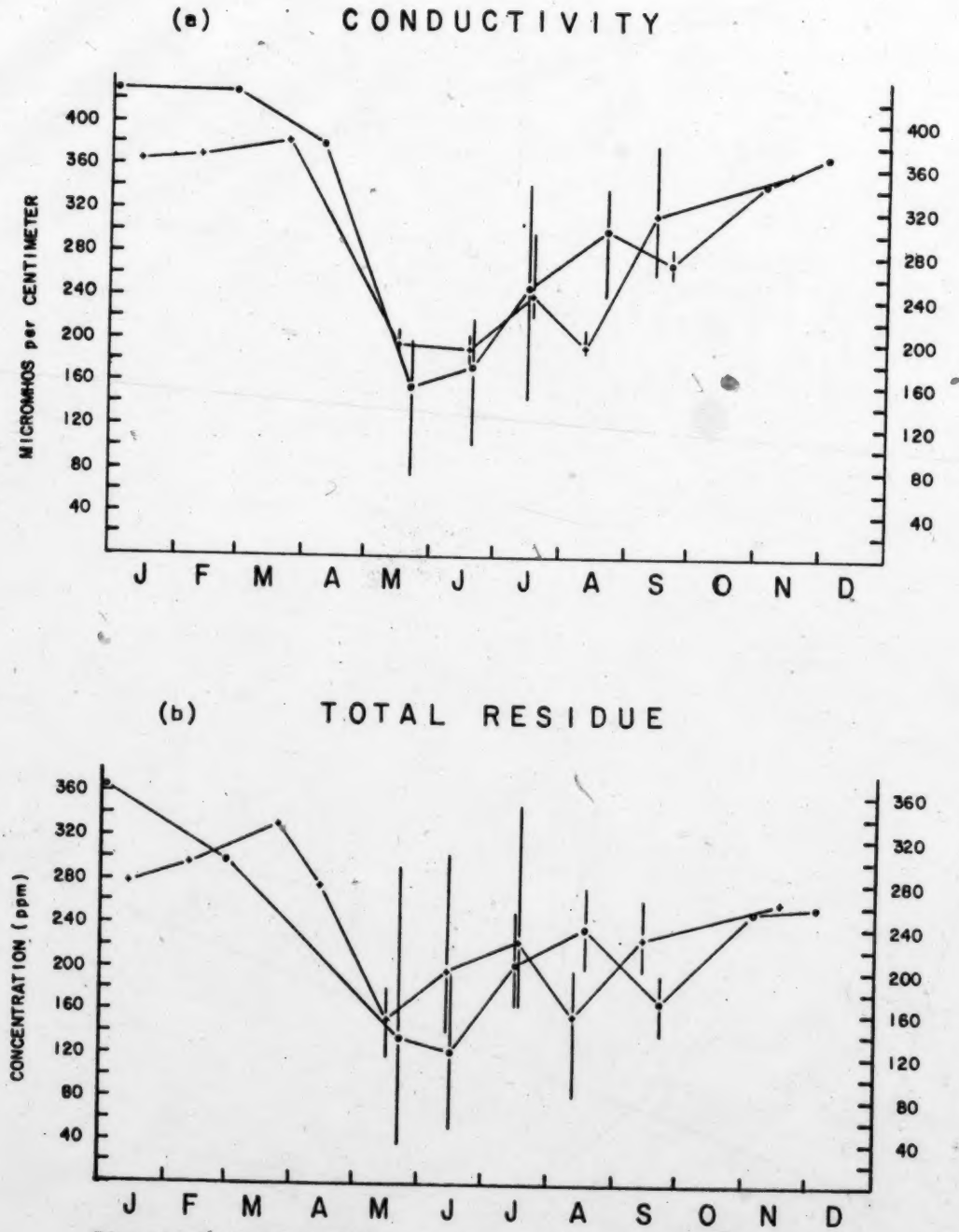



Figure 9 Mean monthly readings for conductivity (a) and total residue (b). Vertical lines represent ranges. o = 1975 data, + = 1976 data.

contributions from this source are probably small.

Results showed concentrations inversely related to streamflow, ranging from 140 ppm in winter to 12 ppm in summer (Fig. 10a). Davis (1972), studying the water quality of streams about 10 km north of Cadomin Spring, found that some of his sites showed this same inverse relationship while other sites showed no relationship. Weisel and Newell (1970), studying headwater streams in the Blackfoot River drainage in Western Montana, found high concentrations at both high and low flows, depending on whether the sulfate source was from surface runoff or groundwater input, i.e. the weathering of metallic sulfides in sedimentary rock.

During the winter of 1974-1975, large growths of *Beggiatoa alba*, a sulfur-oxidizing bacterium were observed (Plate 6). The bacterium thrives in the presence of very low dissolved oxygen concentrations, utilizing most of the available oxygen to oxidize $S^-$ to $S^o$ and then storing the $S^o$ in its cell (Wetzel 1975). This process continues as long as dissolved oxygen levels are low. However, as dissolved oxygen levels increase, oxygen in excess of what the bacteria could use begins to convert $S^-$ rapidly to $SO_4$ leaving less and less $S^-$ available to the bacteria. When the $S^-$ energy source has been depleted, the bacteria must then derive their energy by oxidizing the $S^o$ to $SO_4$. When $S^o$ is also depleted, the bacteria die. This was observed during the spring runoff when dissolved oxygen levels increased. Higher dissolved oxygen levels during the winter of 1975-1976 resulted in very low *B. alba* growth.

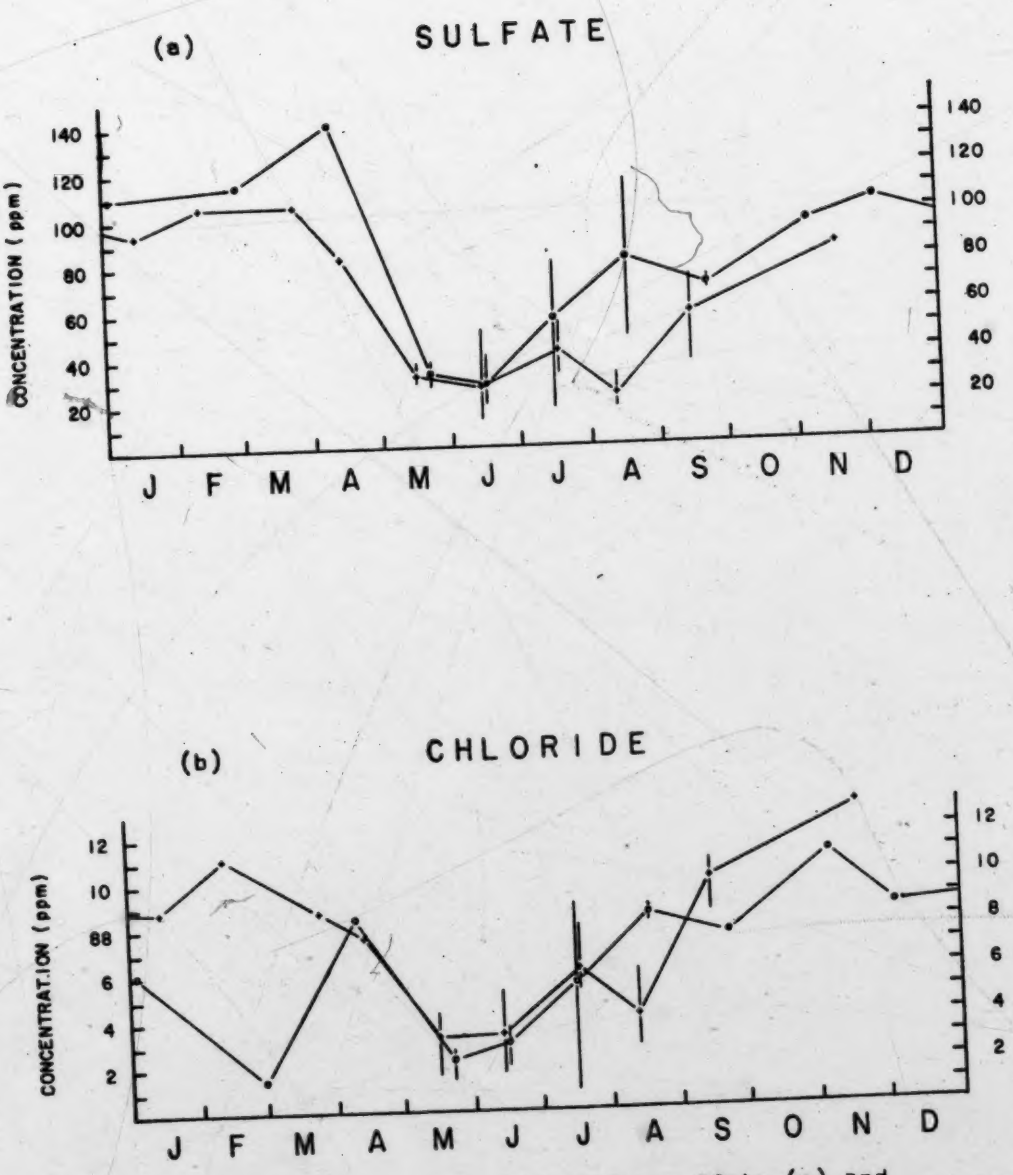



Figure 10 Mean monthly readings for sulfate (a) and chloride (b). Vertical lines represent ranges. o = 1975 data, + = 1976 data.

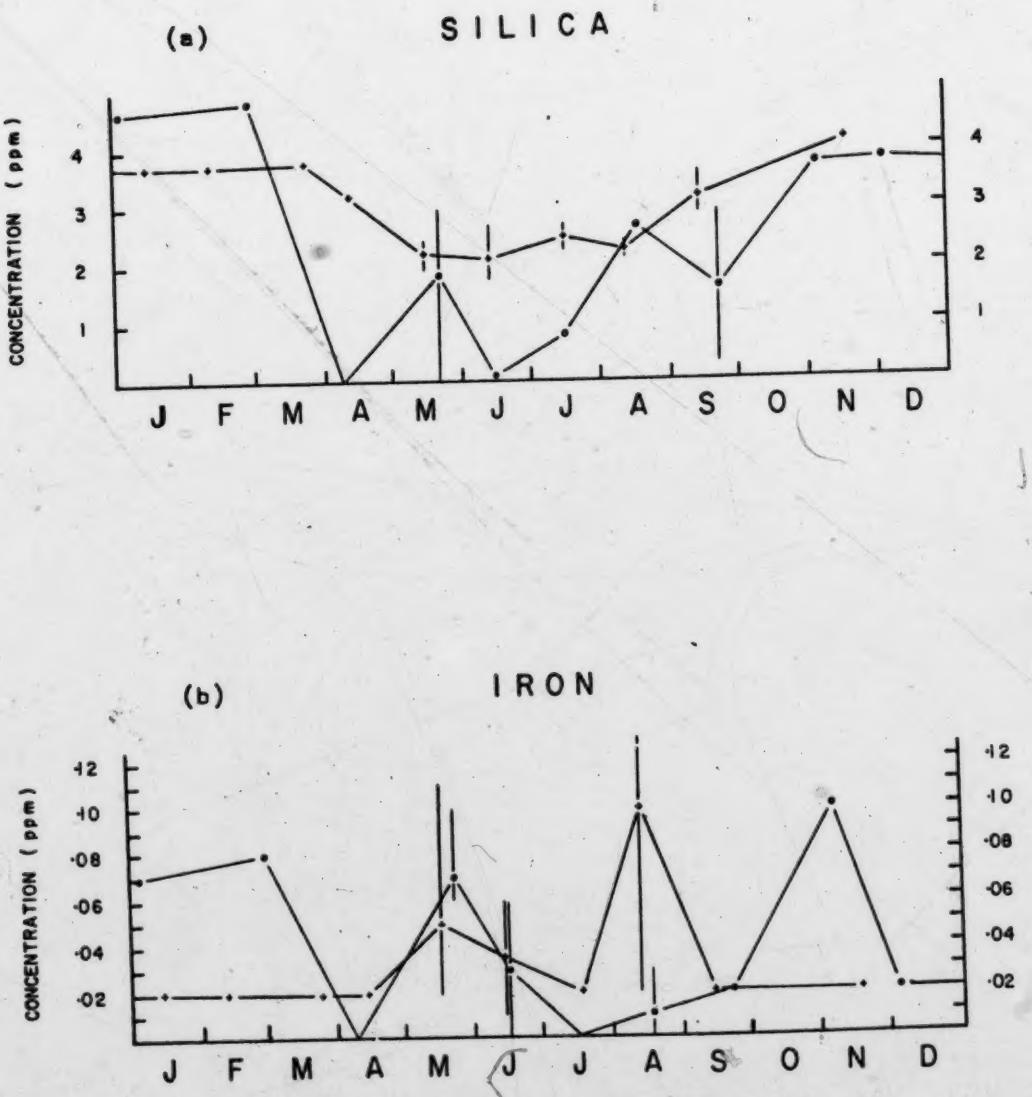



Figure 11 Mean monthly readings for silica (a) and iron (b). Vertical lines represent ranges. o = 1975 data, + = 1976 data.

Chloride, Silica, Iron

Chlorides ranged from 13.1 ppm in winter to 2.0 ppm during spring runoff and storm events (Fig. 10b). During 1975, silica (or $SiO_2$) ranged from undetectable levels to 5.1 ppm; in 1976 the range was 1.7 to 4.1 ppm (Fig. 11a). These results from Cadomin Spring are well below the world average of 13 ppm.

Although iron is abundant in coal deposits that contain pyrite ($FeS_2$), the Cadomin area coal deposits contain only low amounts of pyrite (Berkowitz 1969). Iron ranged from 0.23 ppm following a storm on 5 August 1976 to undetectable levels on a number of occasions in 1975 (Fig. 11b).

Phosphates and Nitrate-Nitrogen

The relative insolubility of phosphate-containing minerals and the loss of surface phosphate via biotic removal and to soil during percolation keeps the phosphate content of groundwater low, its average concentration being about 0.02 ppm phosphorus (Wetzel 1975). Thus, any appreciable concentration above 0.02 ppm total phosphate would probably indicate organic input from surface runoff or precipitation.

In 1975, total phosphate concentration peaked in May when snow-melt occurred (Fig. 12a). A second peak on 3 December is unexplainable. Results in 1976 differed from 1975 in that the expected peak due to runoff did not occur. Orthophosphate was present in amounts too low to detect (by my methods) throughout 1975 and to 5 May 1976 (Fig. 12b). However, on 14 May 1976 and throughout the remainder of the study significant concentrations

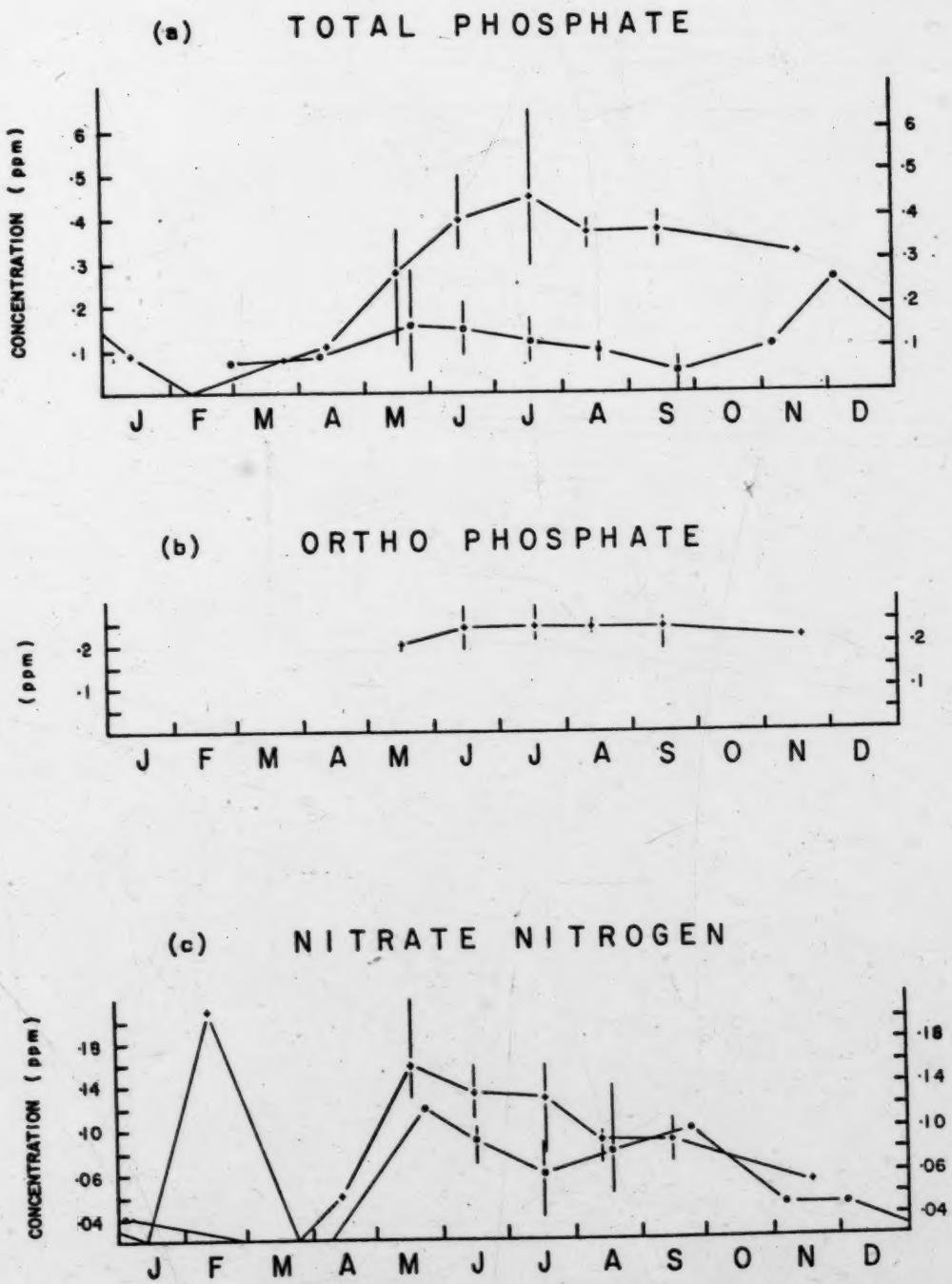



Figure 12 Mean monthly readings for total phosphate (a), ortho phosphate (b), and nitrate nitrogen (c). Vertical lines represent ranges. o = 1975 data, + = 1976 data.

were found, even exceeding the total phosphate readings of 1975. These concentrations were consistent from one sampling date to the next.

During the snow-melt period, nitrate-nitrogen concentrations reached their highest levels (Fig. 12c), probably due to surface runoff. Throughout the remainder of the year, a general decrease was observed and by midwinter nitrate-nitrogen was present in amounts too low to be detected.

Dissolved Oxygen

Dissolved oxygen profiles are shown in Figure 13. Very low concentrations were observed throughout the 1975-1976 winter ($0.8 \pm 1.1$ ppm or $7.3\% \pm 11.0\%$ saturation) with a minimum of 0.1 ppm (1.2 saturation) occurring in both December and January. Concentrations rose rapidly during the spring runoff when oxygen-saturated surface water was incorporated into the streamflow. Mean concentrations throughout spring and summer 1975 and 1976 were $5.4 \pm 2.4$ ppm ($53.9 \pm 20.8\%$ saturation) and $5.9 \pm 2.4$ ppm ($58.1 \pm 21.7\%$ saturation) respectively, with a maximum of 9.5 ppm (88.8% saturation) recorded on 18 June 1975.

When the Spring was not augmented by surface water at regular intervals during summer rains, dissolved oxygen concentrations dropped rapidly. During the dry 1975 summer a concentration of only 1.2 ppm was observed as early as 12 August. In 1976, concentrations also fell sharply from a high of 9.1 ppm recorded on 16 August (following a major storm) to 1.8 ppm (16.8% saturation) by 2 September. Hence the fauna was subjected to very low oxygen

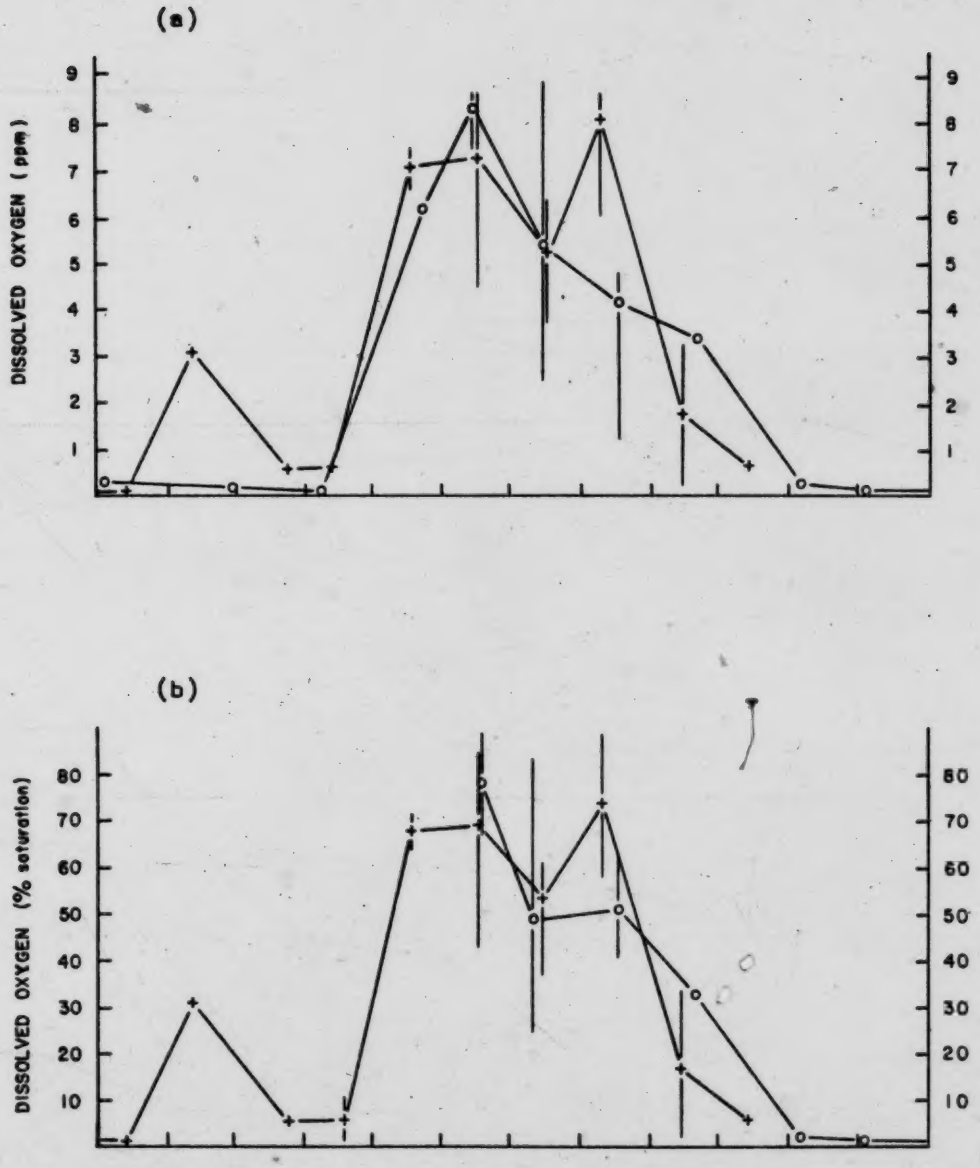



Figure 13 Mean monthly readings for dissolved oxygen.
(a) = dissolved oxygen concentrations
(b) = dissolved oxygen % saturation.
o = 1975 data, + = 1976 data.

Table 2 Dissolved oxygen concentrations (ppm) at various points along Cadomin Spring and in the McLeod River.

| Date 1976 | Source (Site A) | Below Riffle #2 | Below Riffle #3 (Site B) | McLeod River |
|---|---|---|---|---|
| April 4 | 0.2 | 1.2 | 3.0 | 9.1 |
| May 5 | 7.0 | 7.2 | 7.4 | 10.4 |
| May 14 | 7.4 | 7.4 | 7.6 | 10.0 |
| May 19 | 6.6 | - | 7.0 | 11.0 |
| May 28 | 7.4 | - | 7.4 | 10.4 |
| June 8 | 6.3 | - | 6.8 | 9.1 |
| June 17 | 7.8 | - | 8.0 | 10.8 |
| June 23 | 7.8 | - | 7.9 | 10.2 |
| July 6 | 6.2 | - | 7.1 | 11.0 |
| July 23 | 4.2 | 5.6 | - | 11.9 |
| July 29 | 5.7 | - | - | 9.3 |

concentrations in winter and widely fluctuating levels in summer, depending on the size and frequency of storms.

One unusual increase in dissolved oxygen occurred in late January and early February; and, although at this time there was no observable increase in streamflow (Fig. 5) or decrease in water temperature (Fig. 6a), surface water input must have occurred at this time, because of the significant increase in dissolved oxygen concentration. By 23 March, concentrations were once more below 1 ppm.

During 1976, dissolved oxygen readings were taken at various points along the channel in addition to the measurements at the source (Table 2). Of particular significance were the readings on 24 April when dissolved oxygen at the source (site A) was 0.2 ppm (1.2% saturation), 1.2 ppm (10.0% saturation) at riffle #1, and 3.0 ppm (30% saturation) below site B. Thus, in winter, site B's community would never appear to be under the same oxygen stress as site A's community. During the summer when concentrations were higher the increase between the two sites was insignificant.

## Biological Characteristics

### Total Fauna

Five phyla represented by 26 families and at least 57 more definitive taxa were represented in the 144,085 organisms collected (Appendices 14 & 15). However, the majority of the organisms by number (78.28%) were restricted to only three families:

| Family | % Total Number |
|---|---|
| Chironomidae | 36.1 |
| Enchytraeidae | 23.7 |
| Naididae | 18.5 |

The most diverse family was Chironomidae with 27 species (2 known and 25 unknown) found in the Spring. Most of the other recognizable families were represented by only one or two species or genera. I did not attempt to identify the Nematodes and the Hydracarina was identified only to Order.

The total relative abundance of each major taxonomic group is shown in Figure 14, and Figures 15 and 16 show the changes in relative abundance throughout the year. The numbers and biomass profiles generally followed similar shapes; but, because of small organism size, the Naididae and Harpacticoida did not account for much biomass. The converse was true for groups such as Lumbriculidae and Ephemeroptera. Except for relatively more Tubificidae at site A and relatively more Lumbriculidae and Tricladida at site B, both sites exhibited similar relative abundances for the major groups.

Mean organism weight (biomass/total number) was used to compare the standing crop of sites A and B (Fig. 17). The sites with respect to mean organism weight were comparable from October 1975 - February 1976. However, from the latter part of winter to the end of summer, the mean organism weight of site B (0.13 mg) was substantially greater than site A (0.06 mg). This was partially due to the relatively larger Lumbriculidae and Tricladida which were relatively more abundant at site B than site A. However, even when

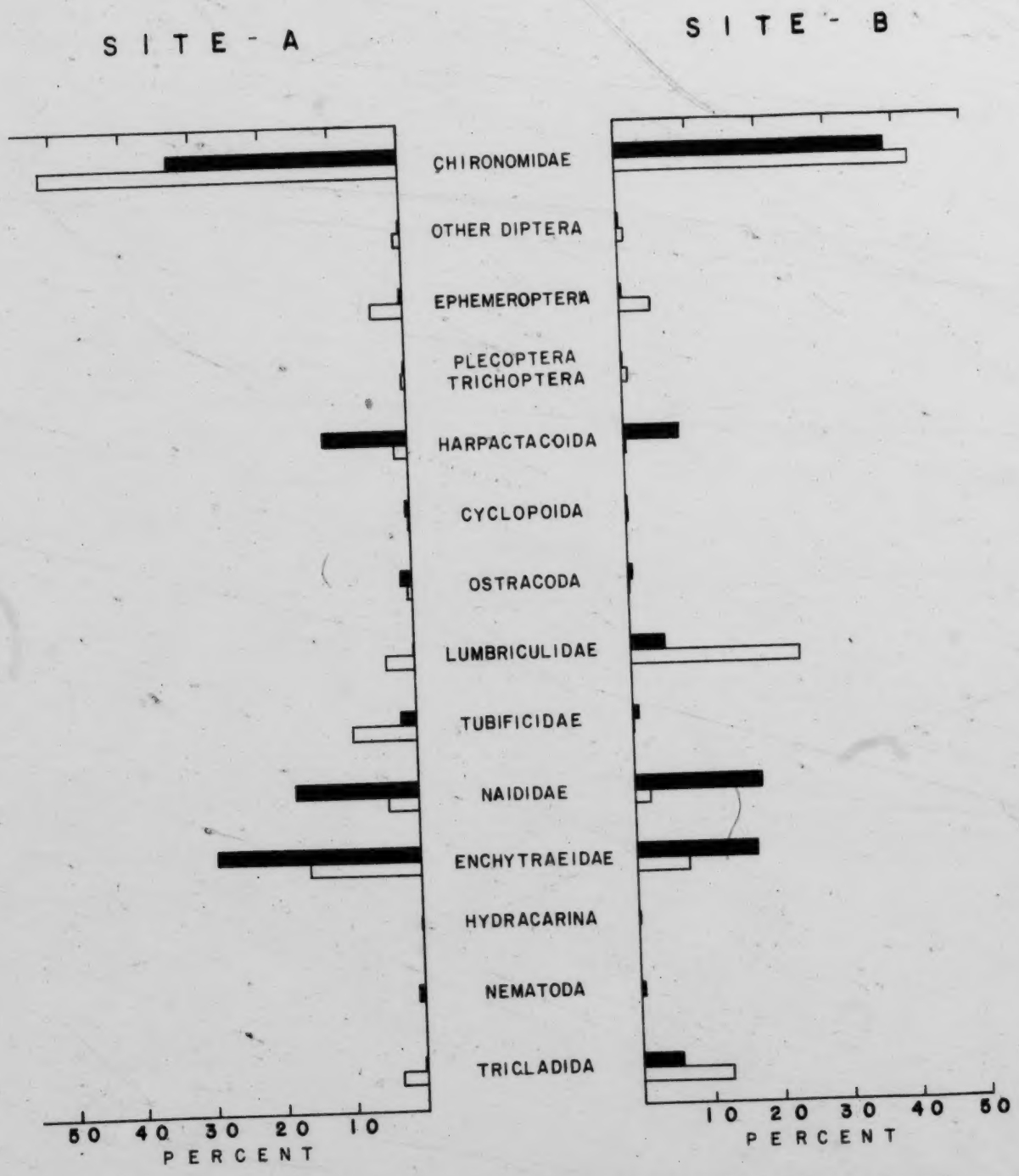



Figure 14 Total relative abundance of each major group found in Cadomin Spring. Numbers are represented by the solid bars and biomass by open bars.

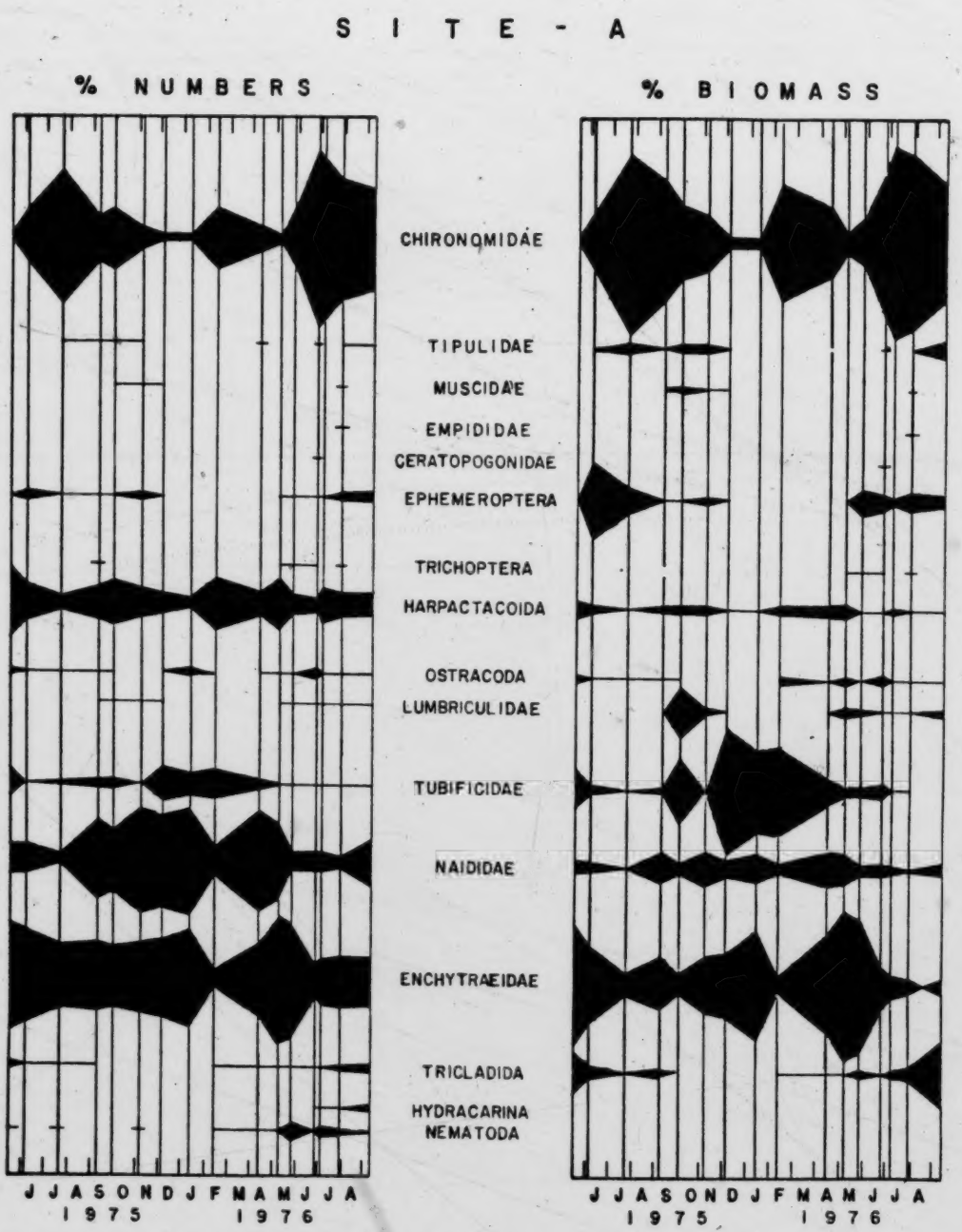



Figure 15 Seasonal relative abundance of major groups at site A. Width of spindle is proportional to the number or biomass of each taxon on a particular date.

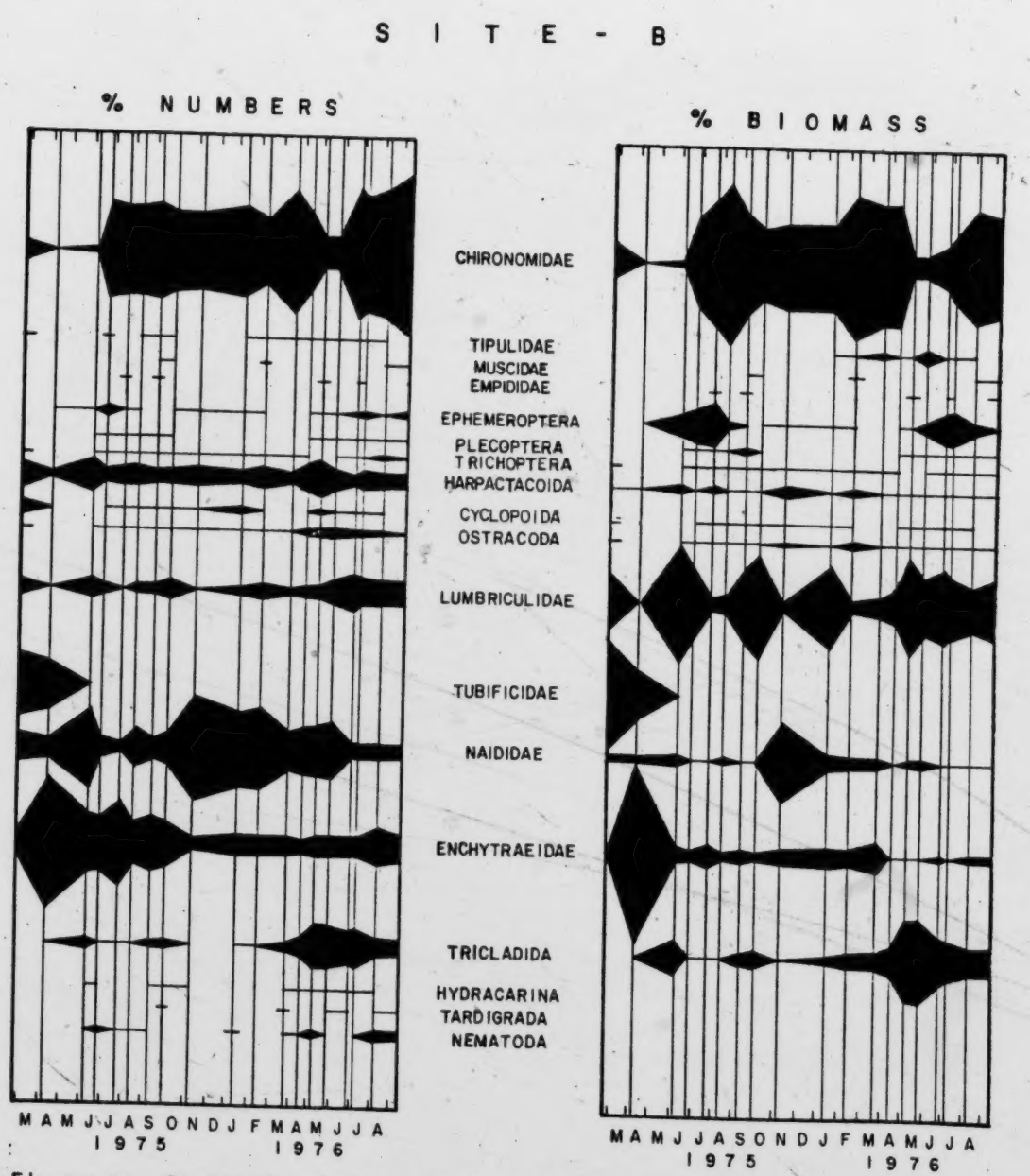



Figure 16 Seasonal relative abundance of major groups at site B. Width of spindle is proportional to the number or biomass of each taxon on a particular sampling date.

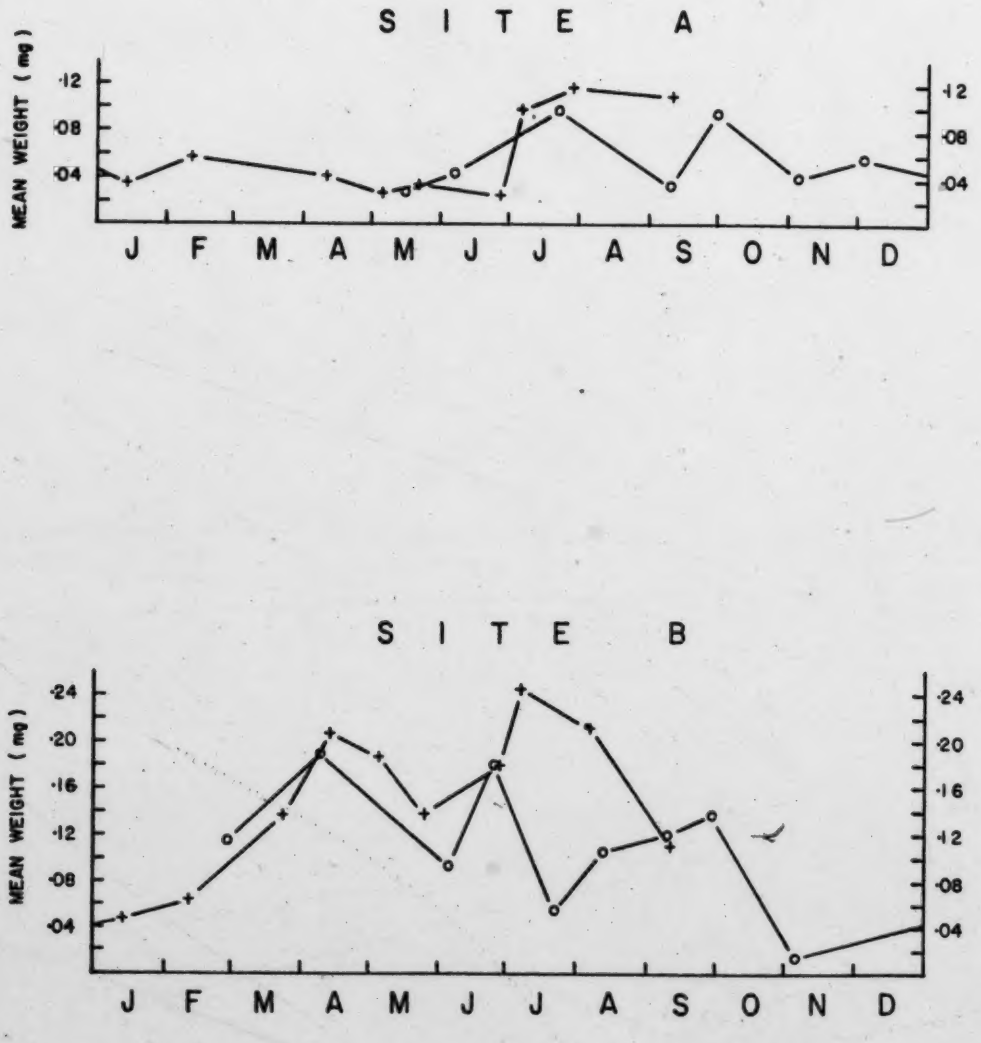



Figure 17 Total mean individual weight (total weight of organisms/total number of organisms) profiles for sites A and B respectively. o = 1975 data, + = 1976 data.

Table 3. Seasonal similarity of invertebrate samples (derived from Appendix ). x = samples from site A; o = samples from site B; a,b,c are sub-clusters of the primary cluster I; d,e are sub-clusters of the primary cluster II.

| | I | | | | | | II | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | a | | b | | c | | d | | e | |
| | 1975 | 1976 | 1975 | 1976 | 1975 | 1976 | 1975 | 1976 | 1975 | 1976 |
| April | o | | | o | | | | | | o |
| May | x | xx | | | | oo | | | | |
| June | x | | o | | | | o | x | | o |
| July | | | | | | | ox | xx | | o |
| Aug. | | | | | | | o | | | o |
| Sept. | | | xx | | | | oo | ox | | |
| Oct. | | | | | | | | | | |
| Nov. | | | x | | o | | | | | |
| Dec. | | | x | | | | | | | |
| Jan. | | | | x | | o | | | | |
| Feb. | | | | | o | ox | | | | |
| March | | | | | | | o | | | |

the biomasses of Lumbriculidae and Tricladida were subtracted from both sites to make the comparison more equitable, the mean weight at site A (0.05 mg) was substantially lower than site B (0.09 mg).

Using percent composition data for numbers (Appendix 10 & 11), a dendrogram, grouping the most similar sampling dates, was derived (Appendix 3). By combining the most closely related sampling dates in the dendrogram into arbitrary groups and then transcribing the groups into a table (Table 3), three general periods, brought about by relative changes in faunal composition, could be indentified: 1) April-June, 2) June-September, and 3) September-April. Dominant groups for these periods were as follows:

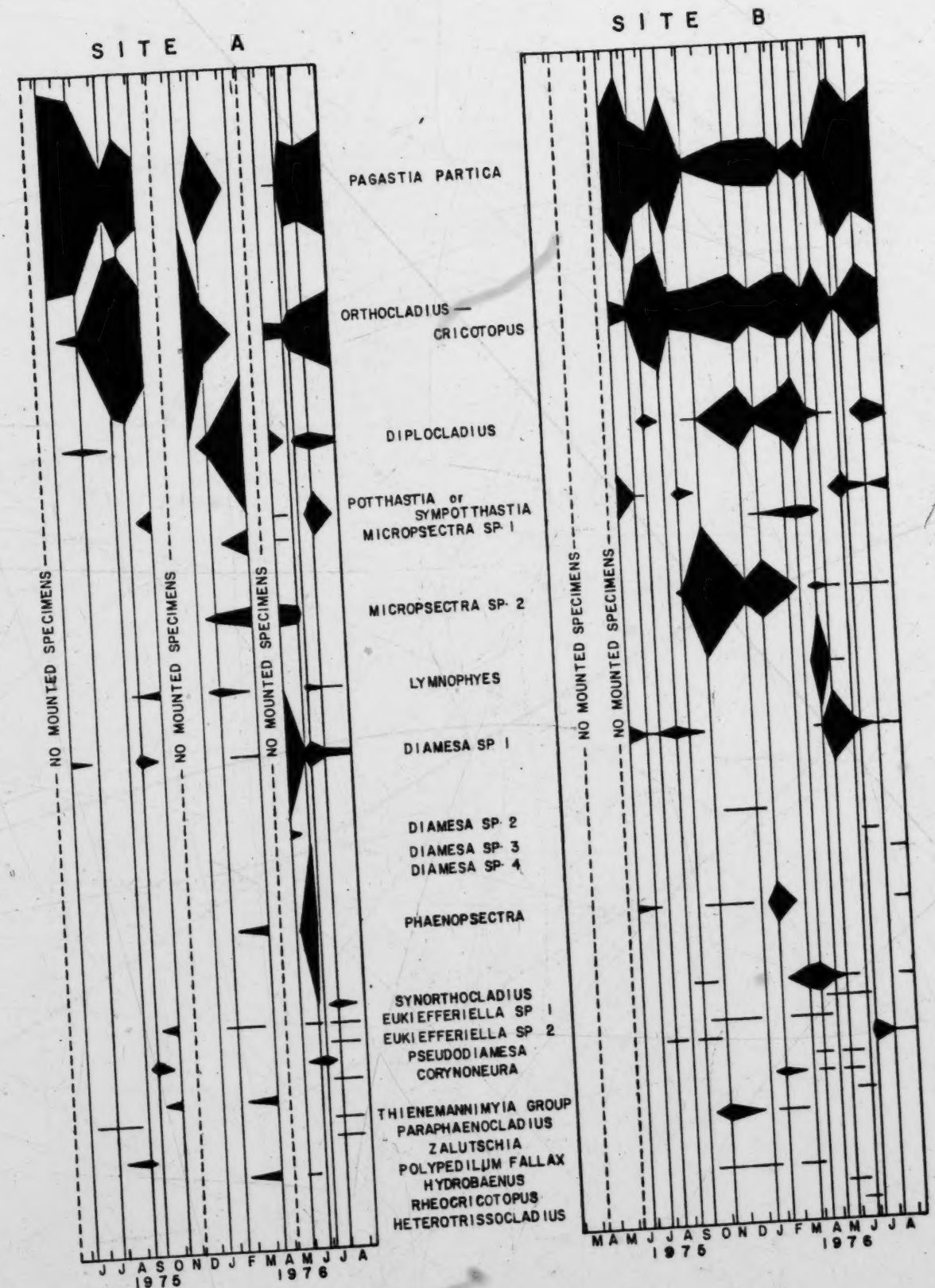
| | Site A | Site B |
|---|---|---|
| April-June | Enchytraeidae | Naididae |
| June-September | Chironomidae | Chironomidae |
| September-April | Naididae | Chironomidae |

Transition periods in April, June and September correspond with major changes in water conditions, i.e. discharge rates and water chemistry. Spring runoff generally begins during April and ends in June with base flow reached sometime in September.

Chironomidae

In Cadomin Spring this cosmopolitan family is represented by 21 genera. Two species, *Pagastia partica* and *Polypedilum fallax*, could be recognized as such in the larval state. There are at least 25 unknown species. Chironomids were the most abundant group accounting for 32.6% and 39.7% of the animals at site A and B,

Figure 18 Relative abundance of each chironomid taxon identified in Cadomin Spring. Width of spindle is proportional to the number of each taxon on a particular sampling date.


SITE A
SITE B
NO MOUNTED SPECIMENS
NO MOUNTED SPECIMENS
NO MOUNTED SPECIMENS
NO MOUNTED SPECIMENS
PAGASTIA PARTICA
ORTHOCLADIUS —
CRICOTOPUS
DIPLOCLADIUS
POTTHASTIA or
SYMPOTTHASTIA
MICROPSECTRA SP. 1
MICROPSECTRA SP. 2
LYMNOPHYES
DIAMESA SP 1
DIAMESA SP. 2
DIAMESA SP. 3
DIAMESA SP. 4
PHAENOPSECTRA
SYNORTHOCLADIUS
EUKIEFFERIELLA SP 1
EUKIEFFERIELLA SP 2
PSEUDODIAMESA
CORYNONEURA
THIENEMANNIMYIA GROUP
PARAPHAENOCLADIUS
ZALUTSCHIA
POLYPEDILUM FALLAX
HYDROBAENUS
RHEOCRICOTOPUS
HETEROTRISSOCLADIUS
J J A S O N D J F M A M J J A
1975
1976
M A M J J A S O N D J F M A M J J A
1975
1976

respectively, and 52.3% and 43.7% of the biomass at site A and B respectively (Fig. 14). At site B, chironomids consistently occurred in relatively large numbers throughout the year except for May (Fig. 16). At site A chironomids were relatively abundant in summer, but in winter, except for February, their relative abundance was low. Also in terms of absolute numbers, few chironomids were recorded from site A during winter and spring.

The chironomids in Cadomin Spring are represented by four subfamilies: Orthocladiinae, Dimesinae, Chironominae and Tanypodinae. Of the 27 chironomid taxa identified, 19 belonged to the primarily cold-water subfamilies, Orthocladiinae (12) and Dimesinae (7); these two subfamilies represented 85% (38% and 47% respectively) of the total chironomids collected. The diamesine *Pagastia partica* alone accounted for 38% of the total chironomid fauna, while the *Orthocladius-Cricotopus* complex accounted for another 26%; thus, these two taxa represent 64% of the total chironomids present. Chironominae had five recognizable genera representing 11% of the fauna, while Tanypodinae with three recognizable genera represented less than 1% of the chironomids collected.

Figure 18 shows the relative abundance of each identified chironomid. *Pagastia partica*, the dominant species, was relatively abundant throughout the summer at both sites and, although reduced in relative numbers, was also present during the winter at site B. However, except for February 1976, it was absent during winter at site A. This might be due to the oxygen deficit observed during low streamflow.

The *Orthocladius-Cricotopus* complex was the only other chironomid taxon (besides *P. partica*) to be found consistently throughout the year (but only at site B). Because this complex represents an unknown number of species, its distribution at site B was relatively uniform through the year. At site A it was found in more samples than *P. partica*, particularly during the winter months, probably because of the suspected large number of species within this taxon. The more pronounced fluctuations at site A compared to site B is a result of the very low numbers of chironomids found at site A.

The other chironomids that were abundant at both sites were *Diplocladius*, *Diamesa* sp. 1, and *Micropsectra* sp. 2. Larvae of *Diplocladius* and *Micropsectra* sp. 2 were important components of the winter communities, but disappeared in summer. *Diamesa* sp. 1 larvae were most abundant during summer, and were also found in relatively small numbers during early spring. Most of the other identified chironomids were insignificant both in terms of numbers and the frequency in which they were found. Undoubtedly some of these chironomids represent the infrequent arrival of females from other sources, these females successfully ovipositing in Cadomin Spring.

Merritt and Cummins (1978) suggest that a characteristic chironomid community contains species at all major trophic levels. The Cadomin Spring genera identified contain species that have been reported to be shredders (decomposing coarse particulate matter), collectors (decomposing fine particulate matter), scrapers (algae consumers), and piercers and engulfers (predators). *Polypedilum*

Table 4 Distribution of Tipulidae genera throughout the sampling period. A = site A, B = site B, x = invertebrate samples from 1975, o = invertebrate samples from 1976.

| | Pedicia | | Antocha | | Ormosia | | Tipula | |
|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B |
| January | | | | o | | | | |
| February | | | | | o | x | | |
| March | | | | | | | | o |
| April | | | | o | | | | o |
| May | | | | o | | | | o |
| June | | | | o | | x | | |
| July | o | | | o | xo | | | |
| August | | | | o | | x | | |
| September | | | | | xo | x | | |
| October | | | | | | | | |
| November | | | | | x | | | |
| December | | | | | | | | |

and *Eukiefferiella* are predatory. Thus Cadomin Spring can probably be identified as having a characteristic chironomid community. However, to properly identify the various food habits of the individual species an empirical study is necessary. Considerable variation in food habits occurs within larvae of a given genus and sometimes within even a species, depending on the given set of environmental conditions (Oliver 1971).

Other Diptera

Tipulids were present in all seasons but never in large numbers. They made up less than 0.1% of the total fauna at both sites. There were larvae of four genera, *Ormosia* being the most frequently encountered (Table 4). *Limnophora* (Muscidae) larvae were present at both sites in summer and fall at site B (but only in July at site A) and absent in winter. Pupae of *Chelifera* were found on 10 September 1976, suggesting that its life cycle can probably be completed in Cadomin Spring.

Ceratopogonidae, Psychodidae and Ephydridae larvae were recorded from Cadomin Spring, but they were rare at both sites, suggesting they represented only adventitious specimens.

Ephemeroptera

Specimens of three families were identified from Cadomin Spring: Siphlonuridae, Baetidae and Heptageniidae. Siphlonuridae was represented by two species, *Ameletus velox* and *A. celeroides* (although the nymphs could not be separated) while Baetidae had

only one recognizable genus, *Baetis*. Heptageniidae also had only one recognizable genus, *Cinygmula*.

Ephemeropteran nymphs were never a major component of the total community, comprising only 0.5% of the fauna by numbers at both sites A and B (Fig. 14). However, mayfly nymphs contributed significantly to the total biomass of the community, about 5% at both sites, with maximum contributions reaching 34% on 6 June 1975 and 24% on 22 July 1975 for sites A and B, respectively.

At site A, ephemeropteran nymphs were found only (except for 11 February 1976) in spring and summer, when dissolved oxygen levels were highest. At site B, they were found year-round, being present in 17 of 19 samples. Also at site B, there was a compositional change from summer to winter, with *Ameletus* dominant in the summer and *Baetis* in winter.

Heptageniidae and Baetidae--Nymphs of Heptageniidae were not a significant component of the ephemeropteran community at either site, although the nymphs were most common at site B. Their presence probably results from the nymphs migrating from the McLeod River and females emerging from the McLeod River and ovipositing in Cadomin Spring. While *Baetis* nymphs were only sporadically found throughout the summer at site B, early instar nymphs were present, albeit in low numbers, throughout the winter (Table 5). Nagell (1973) has shown that smaller nymphs have a greater ability to take up oxygen at low concentrations than larger nymphs. The nymphs' success, therefore, would seem to be at least partially

Table 5 Occurrence of Ephemeroptera nymphs (numbers) in Cadomin Spring. A = site A, B = Site B.

| | Siphlonuridae | | Baetidae | | Heptageniidae | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| 1975 | | | | | | |
| Feb. 27 | | - | | - | | - |
| Apr. 9 | | - | | 1 | | - |
| May 15 | 2 | | - | | 1 | |
| June 5 | | 12 | - | - | | - |
| June 25 | 30 | 25 | - | 1 | 3 | 24 |
| July 22 | 36 | 53 | - | - | - | 1 |
| Aug. 12 | | 10 | | - | | - |
| Sept. 9 | 27 | 41 | - | - | - | 4 |
| Sept. 30 | 13 | 17 | - | 3 | - | 7 |
| Nov. 5 | - | - | - | 2 | - | - |
| Dec. 3 | - | | - | | - | |
| 1976 | | | | | | |
| Jan. 13 | - | - | - | 14 | - | - |
| Feb. 11 | 1 | - | 3 | 1 | 1 | 1 |
| Mar. 23 | 1 | - | | - | | - |
| Apr. 13 | - | 1 | - | 2 | - | - |
| May 5 | - | 3 | 9 | - | - | - |
| May 25 | 14 | 15 | - | - | - | - |
| June 27 | 11 | 79 | 1 | - | - | - |
| July 6 | 14 | 66 | - | - | - | - |
| July 29 | 19 | | - | | - | |
| Aug. 6 | | 14 | | 2 | | 1 |
| Sept. 10 | 10 | 12 | - | 2 | 1 | 21 |

due to their small size and lack of growth in winter.

The disappearance of *Baetis* nymphs during spring and summer, when dissolved oxygen is higher than in winter, seems unusual. However, in view of the propensity of *Baetis* nymphs to exhibit behavioral drift (Waters 1972), combined with the possible catastrophic drift resulting from the spring snow-melt, the few *Baetis* nymphs inhabiting the site were probably carried away. I never found mature (signifying impending emergence) heptageniid or baetid nymphs in Cadomin Spring.

Siphlonuridae--This was the most successful ephemeropteran family in Cadomin Spring, representing 91% and 80% of all the mayfly nymphs from sites A and B, respectively (Table 6). Unfortunately, I was not able to distinguish between the nymphs of *A. velox* and *A. celeroides*.

Migration of *Ameletus* nymphs into Cadomin Spring from the McLeod River began shortly after increased flow from spring snow-melt raised the dissolved oxygen level. Hultin *et al* (1969) and Ulfstand (1968) have suggested that the movement of aquatic insects is usually concentrated into a short period within the migrating insect's life cycle, frequently immediately prior to pupation or emergence. While I did observe large nymphs moving up the channel, none exhibited the dark wing pads that would signify impending emergence. Instead, the migration into Cadomin Spring was more similar, although not as pronounced, to what Clifford (1969) noted for *Leptophlebia cupida*, in which all age classes migrated. Thus, *Ameletus*' migration into Cadomin Spring would appear to be more of

an opportunistic response to an uninhabited area rather than primarily an emergence drive.

I started monitoring migratory movements on 14 May 1976, at which time *Ameletus* was well-established at site B. However, since at this time they were not yet found above site B, the 14 May population at site B probably represented the vanguard of the migration. Five days later, *Ameletus* was found in riffle #2; and by 26 May, the nymphs were observed at site A. Also at this time, last instar nymphs, with darkened wing pads, were observed for the first time close to the shoreline, especially in pool areas, where emergence would take place.

Emergence commenced in early June and continued throughout most of the summer, with peak emergence observed in early July. Large numbers of nymphs were observed transforming on 5 July shortly after 1200 hours. However, I never observed swarming in broad daylight. I could not determine whether the emergence of *A. velox* and *A. celeroides* occurred at the same time. However, there was at least a small overlap between the two species, as I collected adults of both species from rocks in the same area on the same dates.

A comparison of the size distribution histograms of sites A and B showed that site A appeared to have two distinct populations whereas site B, which primarily displayed larger nymphs, had only one (Figs. 19 & 20). It would appear that during the upstream migration the smaller size-class nymphs were precluded from site B because they either lacked suitable habitat or were displaced by

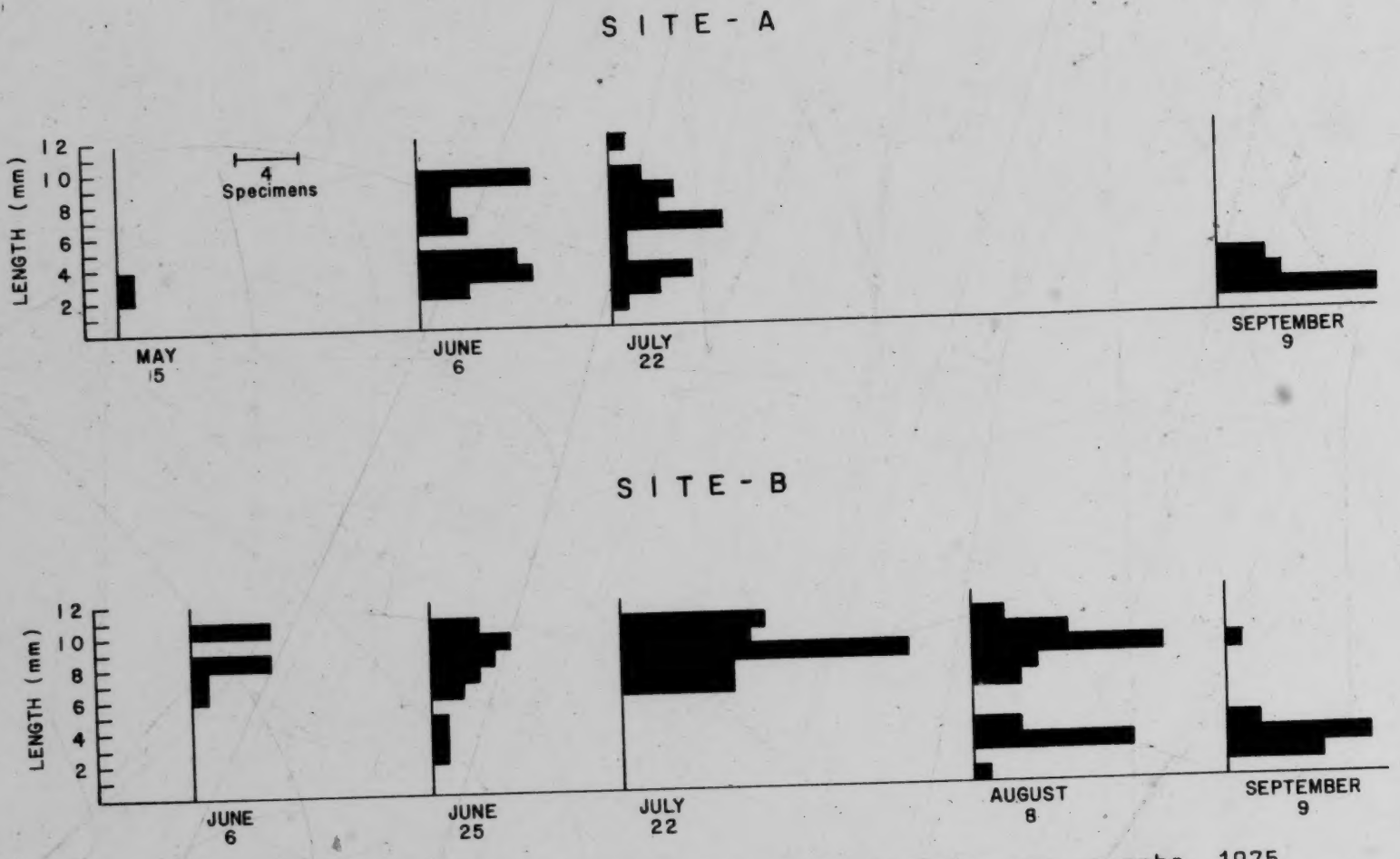
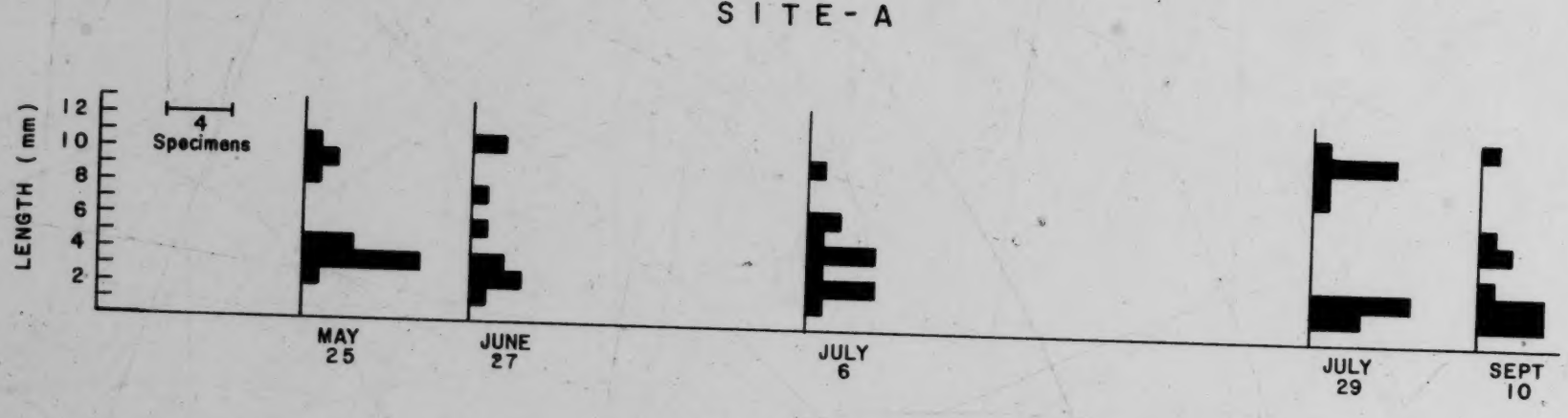



Figure 19 Length-frequency histograms for Ameletus spp. nymphs, 1975.



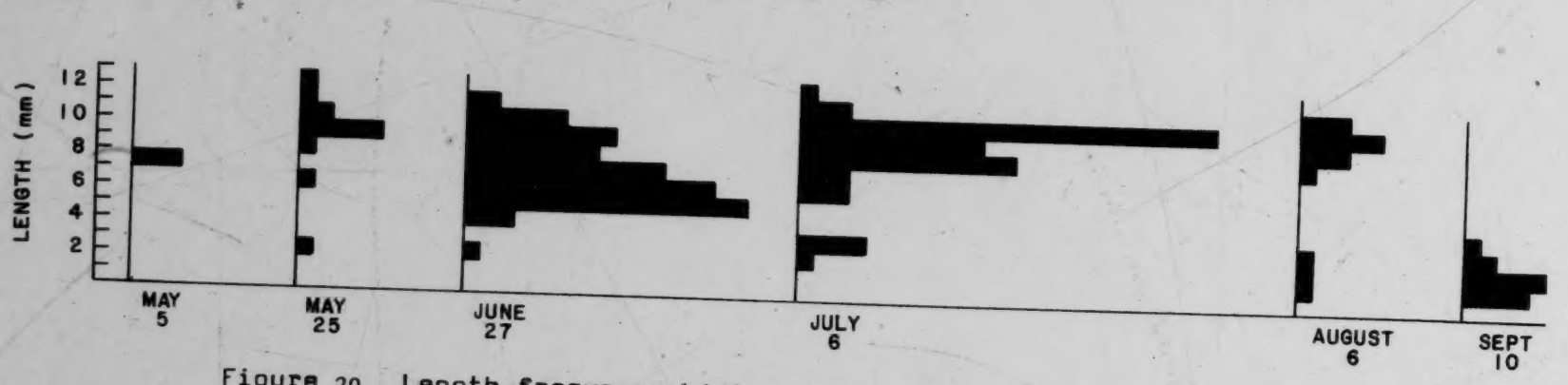




Figure 20 Length-frequency histograms for Ameletus spp. nymphs, 1976.

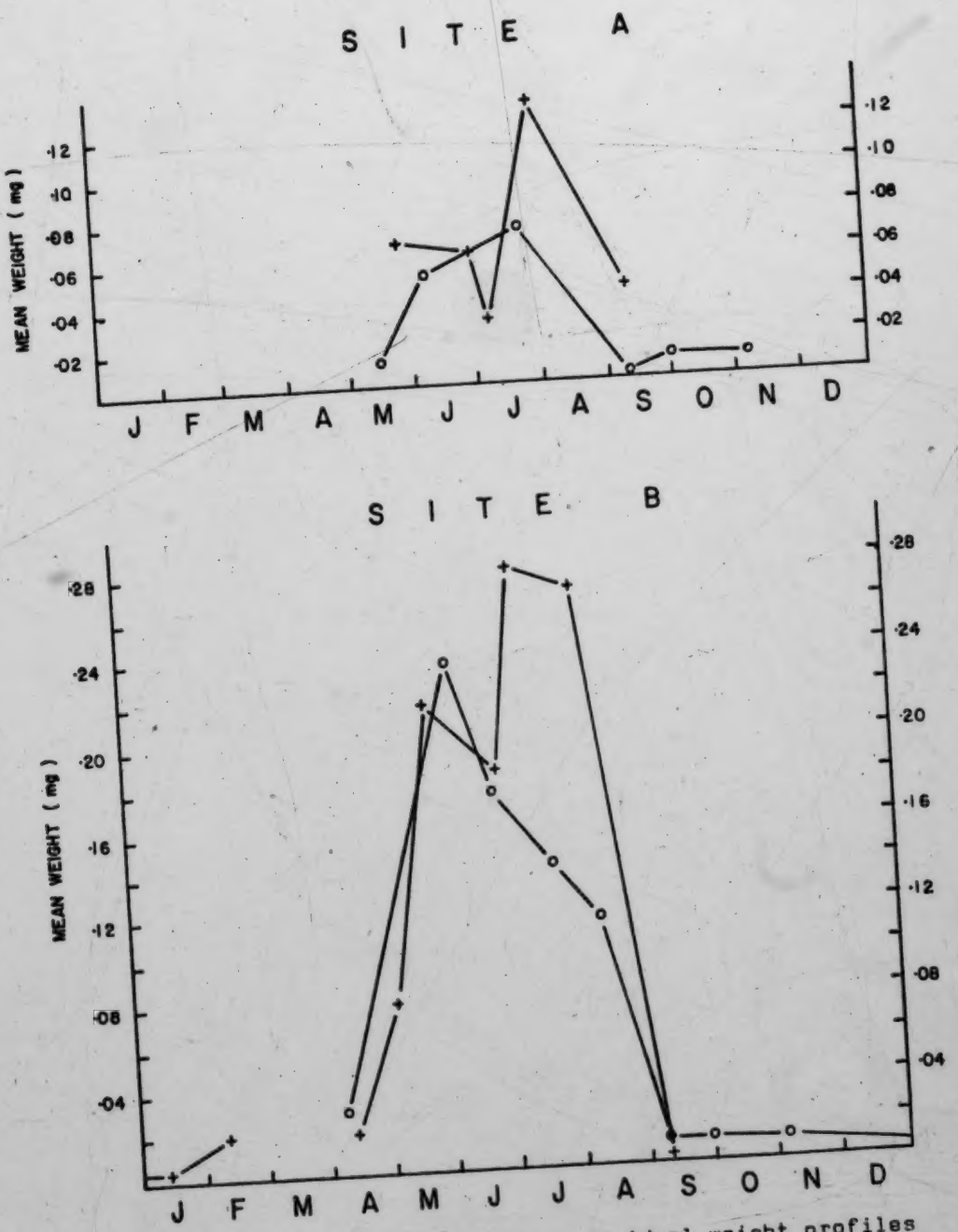



Figure 21 Ameletus spp. mean individual weight profiles o = 1975 data, + = 1976 data.

larger more aggressive nymphs.

Mean individual weight clearly exemplifies the size-class differences between sites A and B (Fig. 21). In 1975, mean weight at site B was three to four times greater than at site A and about two times greater in 1976. The mean weight also peaked about 1 month earlier at site B than site A. These results would suggest that only one species of *Ameletus* inhabited site B, while at site A, particularly in 1975, both species or at least two distinct cohorts of the same species, existed. By August, new generation nymphs were present; and by September, only new generation nymphs remained in the population. I could not determine whether *Ameletus* nymphs perished during the winter. Hynes (1958, 1970) found aquatic insects moving deep into the substrate under adverse conditions and becoming quiescent until the onset of more favorable conditions. This could account for the sudden reappearance of nymphs of all three mayfly families in February 1976, particularly at site A, when dissolved oxygen levels increased, and their disappearance when oxygen levels subsequently dropped during the following month.

Trichoptera

Specimens of three families were identified from Cadomin Spring: Hydropsychidae, Rhyacophilidae and Limnephilidae. The hydropsychids were represented by *Parapsyche*, rhyacophilids by *Rhyacophila*, and limnephilids by *Ecclisomyia*. Trichopteran larvae were never a significant part of the community, comprising less than 0.3% of the total fauna by number at both sites (Fig. 14).

Hydropsychidae and Rhyacophilidae--*Parapsyche* larvae were found twice throughout the study, 30 September 1975 and 10 September 1976, at site B. My specimens were early-instar forms, 2-3 mm in length on 9 September 1975 and 1-2 mm on 10 September 1976. The size of the larvae suggest that *Parapsyche* did not migrate from the McLeod, but came from eggs deposited in Cadomin Spring. Not having collected adults or large larvae, I cannot speculate on when oviposition took place or how long it took the eggs to hatch. However, I am certain that *Parapsyche* did not complete its life cycle in Cadomin Spring.

*Rhyacophila* larvae were also found only twice, 27 February 1975 and 9 September 1975, at site B. In the 9 September sample, there appeared to be at least four species, distinguished by the absence or presence of abdominal gills, gill length, and size and bifurcation pattern of gills. However, I did not collect adults and hence could not determine the species. Probably, the *Rhyacophila* larvae (which do not build cases) migrate up from the McLeod River, as most of them were quite large by the time they were collected.

Limnephilidae--*Ecclisomyia* and *Neothremma* larvae were the only two limnephilids recorded from Cadomin Spring. Both genera have a western distribution, being found in cold, rapid flowing mountain streams (Nimmo 1971). Since I found *Neothremma* larvae only once, 9 September 1975 at site A, its occurrence is considered adventitious. *Ecclisomyia* was also uncommon at site A, being found only once, 10 September 1976.

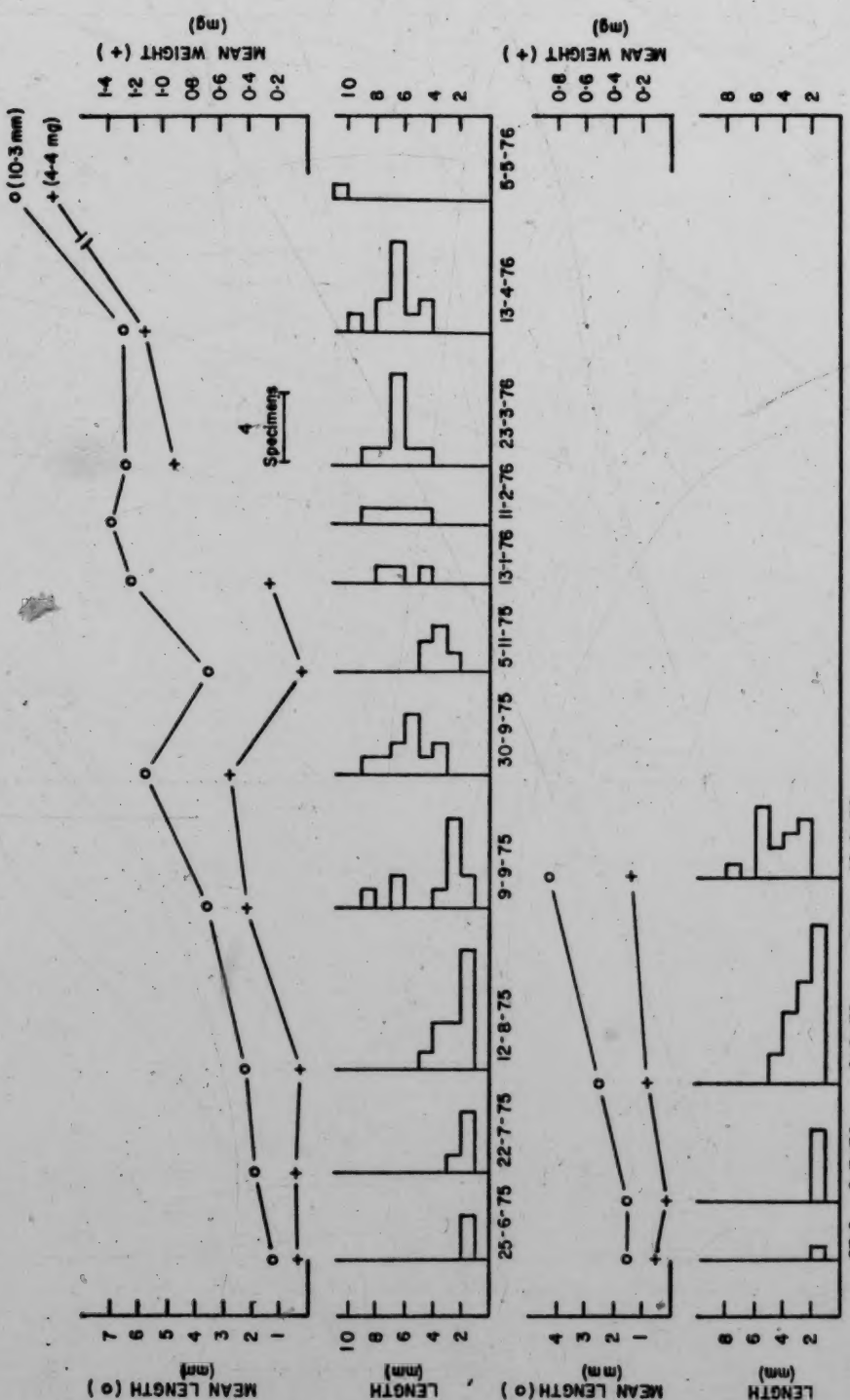



Figure 22 Growth of Ecclisomyia larvae.
o ——— o represents mean length.
+ ——— + represents mean weight.

At site B, *Ecclisomyia* larvae were found in 16 of 19 samples. Although the larvae were always found in small numbers, I was able to determine its life cycle (Fig. 22). The new generation first appeared in late June, with little growth observed throughout July and early August. Growth accelerated during late August and September, but by November the mean size and weight had been reduced substantially. Although this may simply represent a sampling error, the possibility of the arrival of a second cohort should not be discounted. Iverson (1976) observed a similar growth curve for *Agapetus fuscipes* in a Danish Spring; and he identified two cohorts, one hatching in July and the second in November, with the two cohorts becoming indistinguishable just prior to pupation in May. If there were two cohorts in Cadomin Spring, one would expect the first cohort to be hatching in late June and the second in late September and early October, with the initial rapid growth of both cohorts slowing in winter until the two cohorts "merge" just prior to pupation. Reappearance of early instars were observed in late June, and this was similar to their appearance the previous year. Thus, *Ecclisomyia* exhibits an annual cycle.

*Ecclisomyia* larvae survived and even grew at low dissolved oxygen levels in winter. Trichopterans, along with ephemeropterans and plecopterans, have often been considered clean water or pollution intolerant organisms. Indeed, no other trichopteran had any success in Cadomin Spring. The fact that *Ecclisomyia* larvae were absent from site A during the winter but able to complete their life cycle at site B suggests that their dissolved oxygen tolerance level

was somewhere between the undetectable level (the situation at the source in winter) and the 1-3 ppm level present at site B.

Three *Ecclisomyia* species have been described for Alberta and eastern British Columbia (Nimmo 1971). Of the two that have been assigned species names, *Ecclisomyia conspersa* has been recorded from the Cadomin Spring area. Nimmo (1971) observed *E. conspersa* emerging from Whitehorse Creek, about 1 km south of Cadomin Spring, on 24 May 1970. Since the pupal stage of *Ecclisomyia* is 2 or 3 weeks (Wiggins 1978), the observed pupation on 5 May 1976 in Cadomin Spring would coincide with the emergence time of this species observed by Nimmo. The other species Nimmo identified was *Ecclisomyia maculosa*. However, it has been recorded only from the Banff area, emerging in July. Thus the species in Cadomin Spring is probably *Ecclisomyia conspersa*.

Oligochaeta

Lumbriculidae--*Rhynchelmis elrodi* Smith and Dickey was the only representative of this family in Cadomin Spring. And it is the first record of this species in Alberta. The only other confirmed Canadian record of *R. elrodi* is from southern British Columbia in the Fraser River System (Brinkhurst 1978). The species is also found in Washington State, Idaho, Montana, Wyoming, North Carolina, and Alaska (Brinkhurst per. comm.). The lack of recordings of *R. elrodi* in Alberta may be due to large areas still unexplored. However, it is also possible that its absence is due to the last glaciation. Areas where they have been recorded from (Alaska and the Northwestern United States) represent areas that bordered the

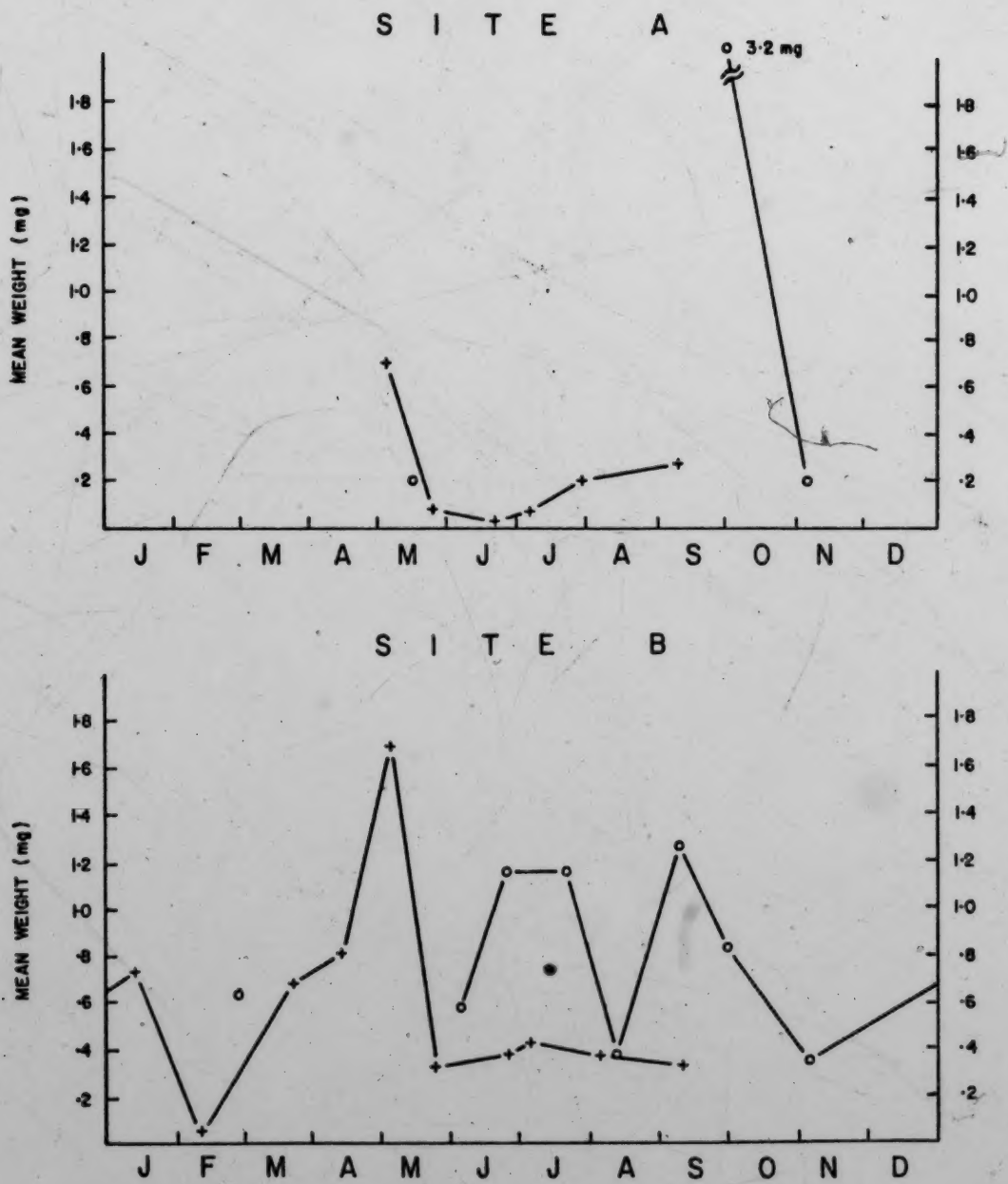



Figure 23 . Mean individual weights of Rhynchelmis elrodi. o = 1975 data, + = 1976 data.

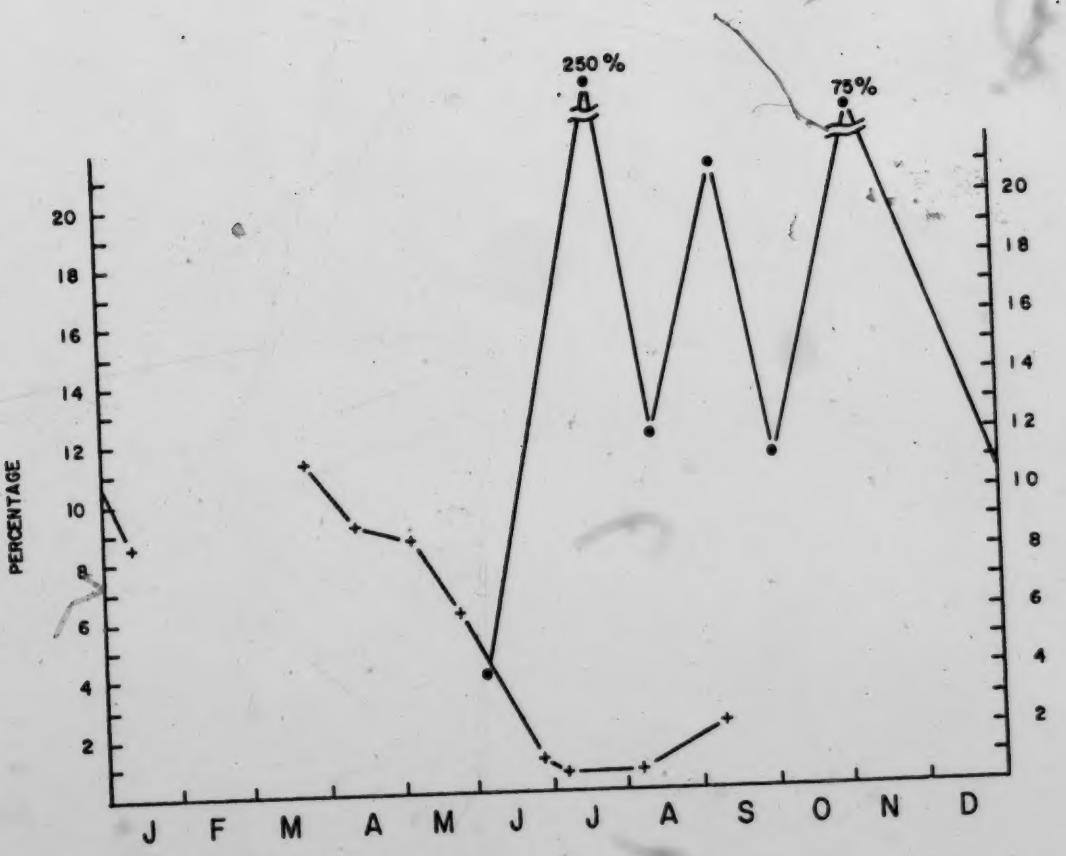



Figure 24. Cocoon: worm ratio for Rhynchelmis elrodi. ● = 1975 data, + = 1976 data.

maximum extent of the Wisconsin Glaciation. Its presence in Cadomin Spring could indicate a possible refugium during the glaciation period. This will be discussed further in the general discussion.

Distribution of *R. elrodi* specimens in Cadomin Spring was skewed towards site B, where 18 of 19 samples contained this species compared to only 9 of 16 samples from site A. *Rhynchelmis* represented 0.1% and 5.4% of the total fauna by numbers from sites A and B, respectively. Because the worms are relatively large, this group was more important in terms of biomass, comprising 4.2% and 25.0% of the biomass of the sites, respectively, (Fig. 14).

Mean individual weight was also greater at site B (Fig. 23). With the exception of 30 September 1975, few large worms were found at site A. Cocoons were not restricted to any one season, but were found sporadically throughout the year, i.e. four of the nine samples containing *Rhynchelmis* at site A also contained cocoons. And on 11 February 1976 at site A, two cocoons were found although *R. elrodi* was not present. The last date *Rhynchelmis* specimens were collected at site A in 1975 was 5 November; they were not recorded again until 5 May 1976. It is possible to gain some insight into *R. elrodi's* life history by looking at the cocoon:worm ratio for site B (Fig. 24). The data do not suggest an annual cycle. Cocoon: worm ratios were comparatively high during the summer of 1975, lower during the 1975-76 winter and lowest during the summer of 1976. The very large ratios observed on 22 July and 5 November 1975 resulted from an unusually low number of worms collected. Also, the 22 July

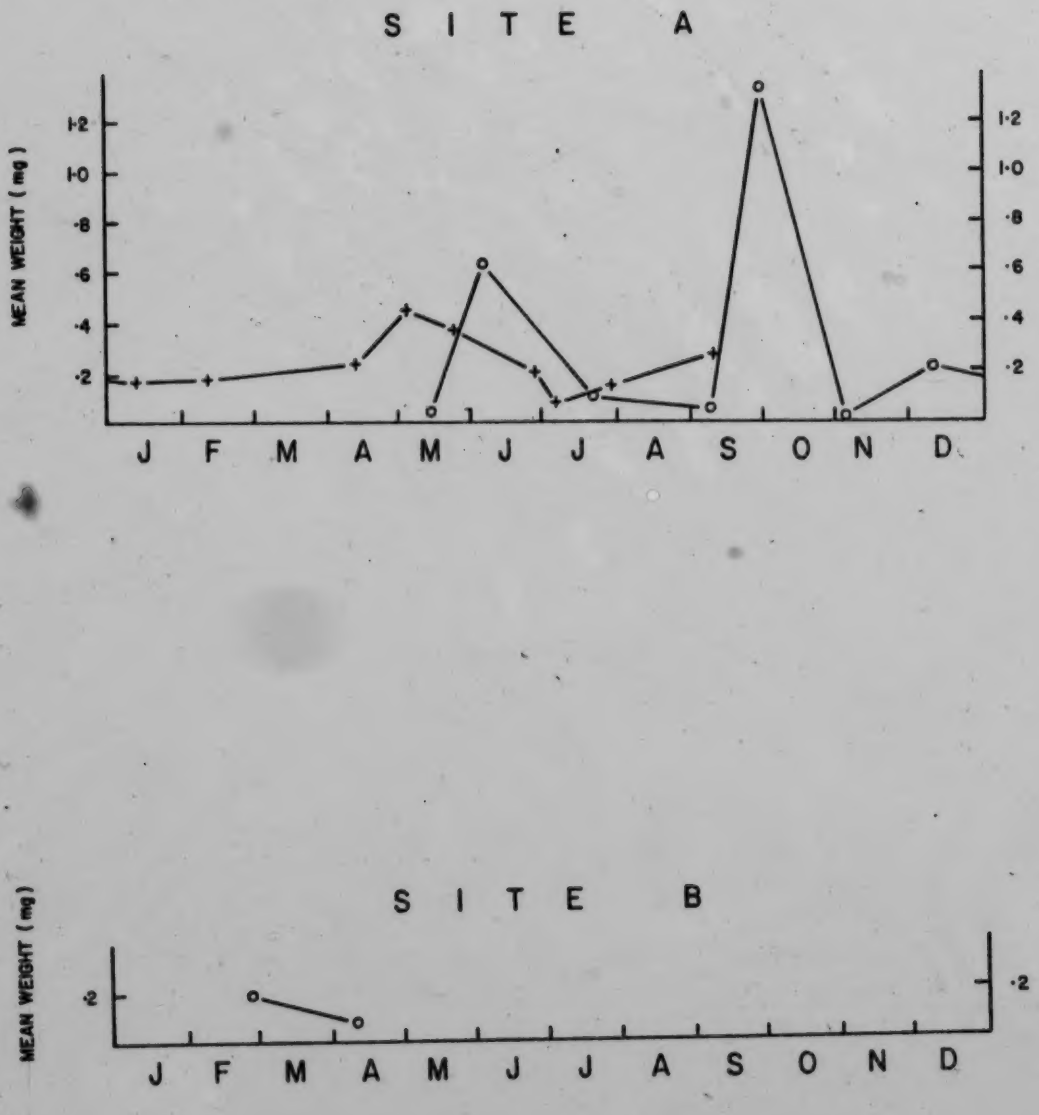



Figure 25. Mean individual weight profiles for Limnodrilus hoffmeisteri. o = 1975 data, + = 1976 data.

sample, when compared to the 5 November sample, contained larger and more mature worms. Beginning on 22 July 1975, samples showed a general increase of immature:mature worms, culminating in a maximum proportion of immature worms in July 1976. There was also a concomitant reduction in mean weight from the summer of 1975 to the summer of 1976, but an increase in relative abundance (Fig. 16). With the exception of 5 November 1975, there was a general agreement between the profiles of mean weight and the cocoon:worm ratio.

I suggest that either the 1975 *Rhynchelmis* population was reaching the end of its cycle or an unknown factor, e.g. predation, reduced the survival of the juveniles in the 1975 population.

Tubificidae--The tubificids were represented by the cosmopolitan *Limnodrilus hoffmeisteri* Chaparede. In contrast to *Rhynchelmis elrodi*, *L. hoffmeisteri* specimens were found predominantly at site A, being present in 15 of 16 samples as compared to only 2 of 19 samples from site B (Fig. 14). In terms of relative abundance, *Limnodrilus* was most important during midwinter, where from December through February it represented 12.5% of the total fauna by numbers and 44.9% by biomass (Fig. 16). Throughout the remainder of the year, *Limnodrilus* specimens usually accounted for less than 1% of both biomass and numbers.

*Limnodrilus*'s success during winter at site A appears to be related to its ability to survive and even reproduce under conditions of low dissolved oxygen concentrations (Aston 1973). Because of this ability, *L. hoffmeisteri* specimens, along with *Tubifex tubifex*, have

often been used as indicator organisms assessing organic pollution (Brinkhurst 1966, Kennedy 1966). It is not so much the worms' ability to thrive under low oxygen to anoxious conditions as it is its ability to survive when their less tolerant predators or competitors are eliminated, allowing the worm population to grow unchecked.

I could not determine the life history of *L. hoffmeisteri* because no cocoons were found, and I did not dissect the worms to determine the presence of mature reproductive structures. The absence of cocoons is somewhat a mystery as my sampling procedure readily picked up *R. elrodi* cocoons. However, Kennedy (1966), remarking on the absence of *Limnodrilus* cocoons from one of his study areas, concluded they had simply been overlooked, since *L. hoffmeisteri* is not known to reproduce without cocoon production.

Despite the lack of cocoons, conclusions on reproductive activity of *Limnodrilus* might be drawn by observing the mean individual weight, the suggestion being that the larger the mean individual weight, the larger the average size of the worm and therefore, the greater the probability of sexually mature worms. Two distinctive peaks, a small one in the spring and large one in late summer-early fall, were observed (Fig. 25). Kennedy (1966) noted that habitat productivity is important in determining the onset of sexual reproduction . More productive habitats caused worms to breed when their ages were less than 1 year and breeding occurred through the year, while in less productive areas worms did not breed until they were at least 1 year old and then in shorter, more seasonal periods.

I can not explain the disappearance of *L. hoffmeisteri* specimens from site B after 9 April 1975. Predation may have been responsible for this; however, it is difficult to visualize such a strong selection for *L. hoffmeisteri* specimen as opposed to *R. etrodi*, which was such a prominent part of the community. Although I did not study the food habits of these two species, their mean weights peaked at approximately the same time, suggesting similar life history patterns. Perhaps competition was important in eliminating the *Limnodrilus* population from site B.

Naididae--Two naidids were identified from Cadomin Spring. *Nais elinguis* Muller occurs throughout the United States (Brinkhurst 1978) and is also considered one of the most common naidids of Europe (Stephenson 1930). In Canada, it has been recorded in New Brunswick, Ontario, Alberta and British Columbia (Brinkhurst 1978). This is the first record of *Chaetogaster diastrophus* (Gruituisen) from Canada. This is surprising as the species is widespread throughout the United States (Brinkhurst 1978). In fact only one *Chaetogaster* species, *C. cristallinus*, from the Yukon and N.W.T., has been recorded from Canada.

*Chaetogaster diastrophus* specimens were collected infrequently and always in very low numbers. Thus, my analysis and discussion will be restricted to the *Nais elinguis* population. Total relative abundance of *N. elinguis* specimens was similar at both sites. *Nais* accounted for about 18% of the total fauna by numbers at each site. *Nais* was the second most abundant taxon at site B and the third most abundant taxon at site A. However, because of their small size, they

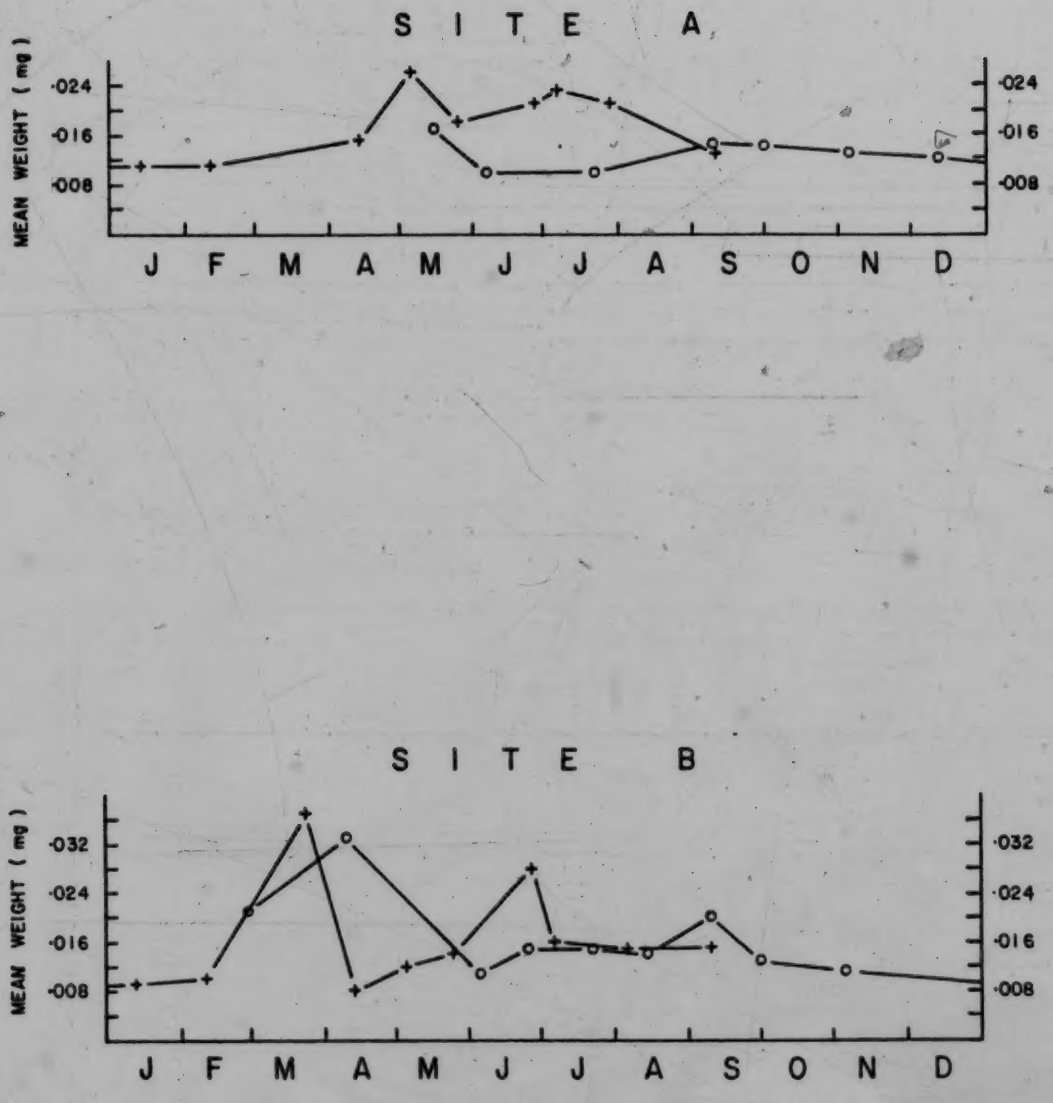



Figure 26 Mean individual weight profiles for Nais elinquis. o = 1975 data, + = 1976 data.

contributed substantially less total biomass, 4.5% (site A) and 2.2% (site B) (Fig. 14).

Although the *Nais* specimens were found throughout the year, they were relatively most important in winter, at which time they accounted for 35.4% of the total fauna at site A and 31.3% at site B (Figs. 15 & 16). Their presence during winter when dissolved oxygen levels were low would agree with the observations of Brinkhurst and Jamieson (1971), who reported large numbers of *N. elinguis* frequently being found in organically polluted rivers.

I used mean individual weights to assess *N. elinguis'* life history (Fig. 26). Naidid populations reproduce asexually by fission (Stevenson 1930); therefore, mean individual weight would be greatest just prior to fissioning and least immediately after separation. Thus, growth periods could be defined as periods of increased mean individual weight.

Results from 1975 and 1976 indicate a major growth period for *Nais* during late winter at site B and spring at site A. In 1976, a second minor peak was observed during late June at both sites; however, the summer peak appears contingent upon environmental conditions rather than part of a regular cycle, as summer peaks did not occur in 1975. While the profiles from both sites generally followed similar patterns, growth appears to be somewhat less at site A when compared to site B. The larger peaks and greater overall fluctuation at site B might suggest that

the worms are growing larger and more are involved in reproductive activity at site B. From February to September 1976, mean individual weight ranged from 0.01 - 0.03 mg with a mean of 0.02 mg at site A compared to 0.01 - 0.04 mg with a mean of 0.02 mg at site B.

During winter, mean individual weight at both sites was similar and without major changes, suggesting a quiescent period. Thus, the increase in relative abundance of *N. elinguis* specimens in winter, as noted earlier, would probably indicate a decrease in the other organisms, many of which are less tolerant to the low dissolved oxygen condition, rather than an absolute increase in the *Nais* population.

I suggest that the *Nais* population in Cadomin Spring has one major growth period per year, in late winter or early spring or both, although smaller fluctuations, presumably caused from environmental conditions, might occur throughout summer. There appears to be little growth throughout most of winter.

Enchytraeidae--One genus, probably *Enchytraeus*, represented this family in Cadomin Spring. Because most of these oligochaetes are semi-aquatic, little work has been done on them. Specimens were sent to Brinkhurst in Victoria but he was not able to positively identify them beyond the family level. Also, he was not able to give me the name of any specialists who could be of assistance.

Jefferson (1976) suggested that at least some British enchytraeids are troglophiles (animals capable of completing their life cycle in epigean, endogean or hypogean habitats) and Ladle (1971)

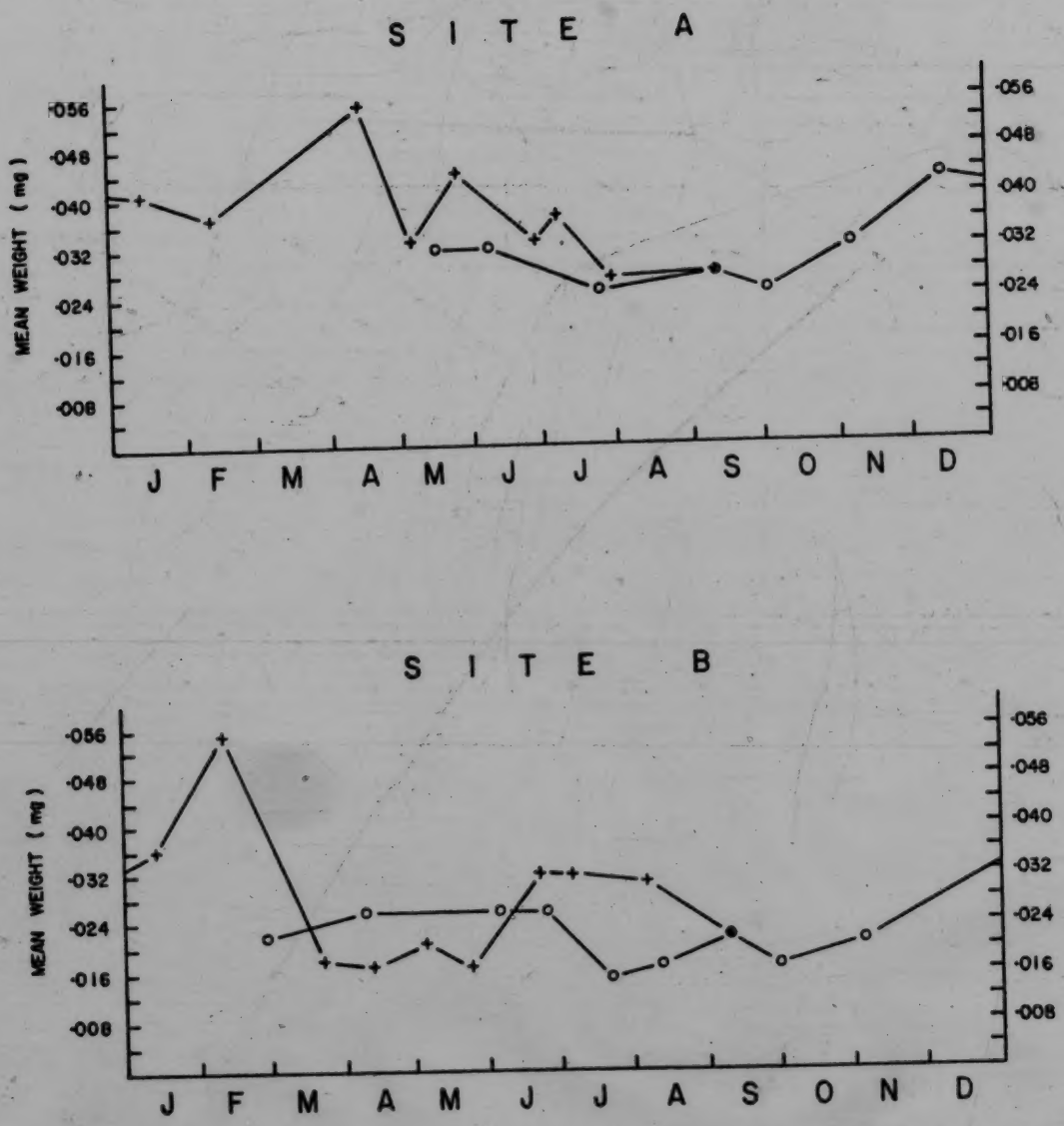



Figure 27. Mean individual weight profiles for Enchytraeidae. o = 1975 data, + = 1976 data.

listed enchytraeids among the oligochaets that he obtained from phreatic water of a gravel bed in Hampshire, England.

All samples from sites A and B contained enchytraeids. Their total relative abundance by numbers was 29.7% (site A) and 18.4% (site B). Total relative biomass was 12.1% (site A) and 7.9% (site B) (Fig. 14). Maximum relative abundance occurred during the spring, with the enchytraeids making up a larger component of the community at site A than at site B (Fig. 15 & 16).

The presence of Enchytraeidae during fall and winter is of interest, because they are not known to tolerate low dissolved oxygen concentrations. The enchytraeid *Lumbricillus* has been found associated with sewage;although the worms apparently still require an abundant supply of dissolved oxygen, since they were found only on substrates that had been re-oxygenated by sprayer systems (Stephenson 1930). Thus, in Cadomin Spring, one would expect enchytraeid numbers and hence their relative importance to decrease in fall and winter. But this was not the case, particularly at site A where dissolved oxygen levels were lowest. Mean individual weights of enchytraeids generally increased during fall and winter, with peaks in February (site B) and April (site A) (Fig. 27). The subsequent decrease in mean weight during summer resulted from an influx of juvenile worms. This suggests that survival and even growth were unaffected by the low dissolved oxygen levels, although reproductive activity might have been inhibited.

Despite mature worms being found throughout the year, cocoons were never collected. It seems unlikely, therefore, that cocoons were

produced in the riffle areas, unless my mesh size was too large to collect them. Brinkhurst (1971) indicated that, except for freshwater species of *Propappus* and marine species of several genera, few species can be regarded as primarily aquatic. Instead, they occupy semi-aquatic habitats among mosses and other vegetation along the shore. Lindegaard and Thorup (1975) found enchytraeids associated almost exclusively with moss in a Danish Spring. One moss sample taken from the shoreline near the source of Cadomin Spring did reveal an unusually large number of enchytraeids, although no cocoons were found.

Tricladida

*Polycelis coronata* (Girard), a common mountain stream flatworm, was the only triclad in Cadomin Spring. It was found in 75% and 84% of the samples from sites A and B respectively, being absent at both sites in winter. *Polycelis* was relatively much more abundant at site B, where it represented 5.8% of the fauna by numbers and 13.3% of the fauna by biomass (Fig. 14). At site A, *Polycelis* accounted for only 0.5% by numbers and 3.8% by biomass. Thus, most of the population was restricted to site B. Because of this, analysis of *P. coronata* data will be based only on the site B samples.

Two apparent growth periods were observed, one in late winter-early spring, peaking in May, and a second shorter period in September (Fig. 28). I say "apparent" because without length frequency histograms I could not determine whether changes in mean weight were due to 1) simply a loss of animals from the smaller size

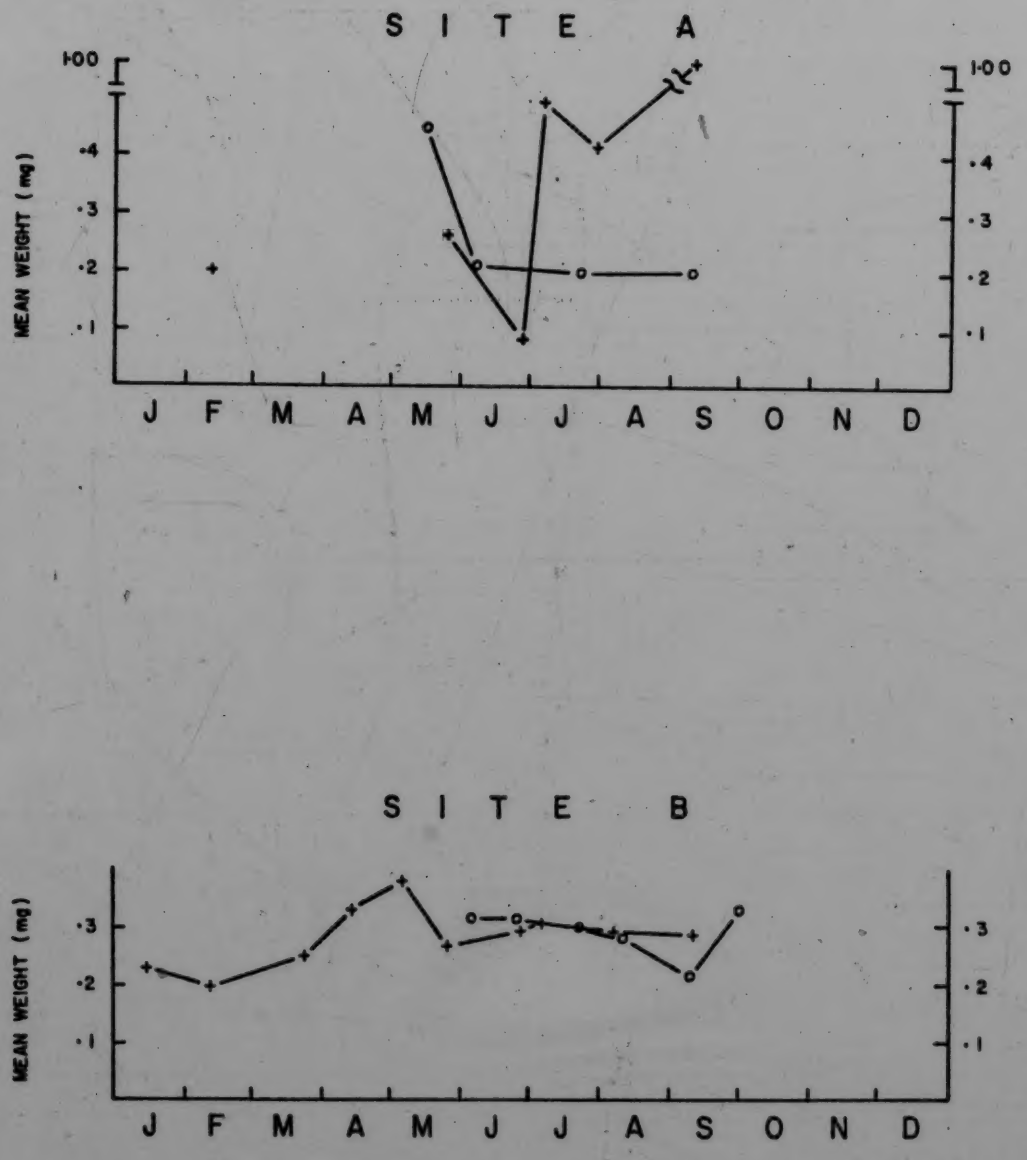



Figure 28 Polycelis coronata mean individual weight profiles. o = 1975 data, + = 1976 data.

classes, with no increase in the larger size class, or 2) both a loss from the smaller size classes and an increase in the larger size classes, or 3) only an increase in the larger size classes. Because of this uncertainty, I collected live specimens for measurements during summer, 1976 (Fig. 29). The size-class distributions remained essentially the same over the entire sampling period. During this period, no specimens over 11 mm in length were collected. Thus the population appears to be "static" in summer, and this would agree with the mean weight data during this period (Fig. 28).

There did appear to be changes in the size-class structure for the 17 November sample. The largest and smallest size-classes were eliminated, leaving only the middle classes, which had a mean length that was essentially the same as that observed throughout the summer. If this condition persists throughout winter, it would at least partially explain why the mean weights remain relatively constant during the winter and why there is little difference between the mean weights of the winter and summer samples. I do not know the fate of specimens in the largest and smallest size-classes.

The length-frequency histograms indicate that the mean lengths of *P. coronata* specimens of Cadomin Spring was smaller (no worms above 11 mm were collected) than those reported by Hyman (in Ward and Wipple 1959), who records the length of mature *P. coronata* as 15-20 mm. Thus, it appears that the constant low temperature of Cadomin Spring has an inhibiting effect on the growth of *Polycelis*. The low temperatures probably also affect the worms' reproductive strategies.

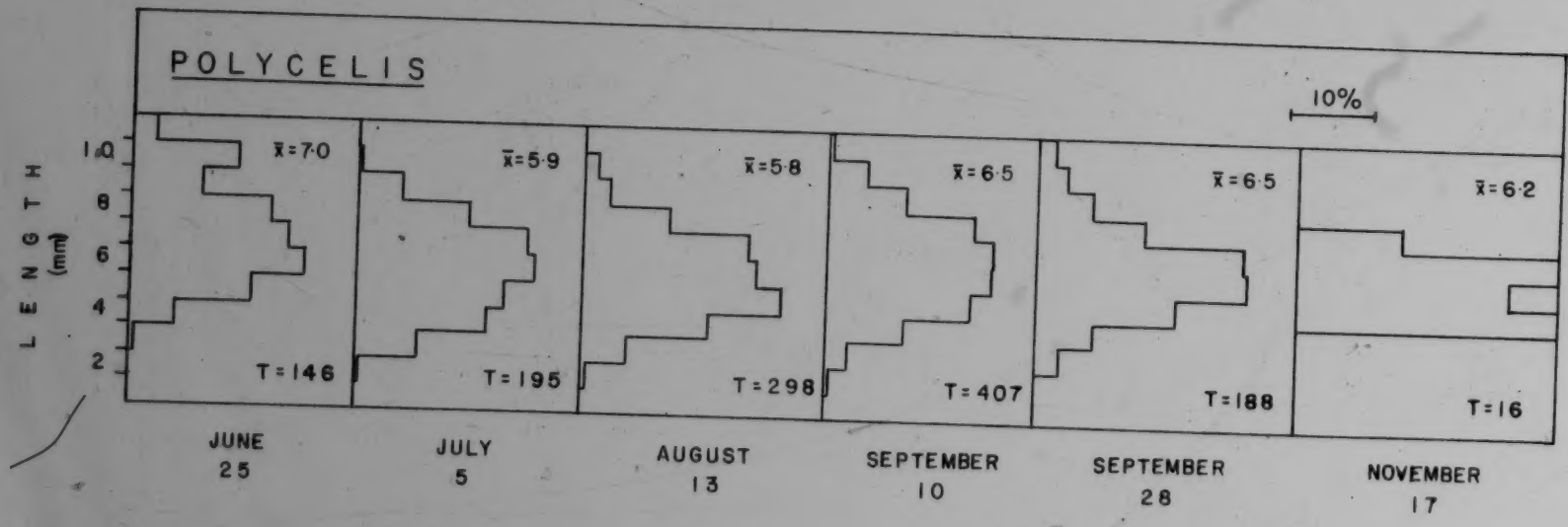



Figure 29 Percentage length-frequency histograms of live specimens, summer 1976. T = total number measured, $\bar{x}$ = mean length of sample.

Folsom (1977) found that sexual reproduction in *Dugesia tigrina* occurred only when the worms were almost full-grown and the water temperature reached a specific level (between 16-20°C). I never collected cocoons;but, since they are probably unstalked (Hyman 1931), it is unlikely that I would collect them by my sampling methods. Nevertheless, *P. coronata* specimens do reproduce asexually in Cadomin Spring, since I collected fissioning animals throughout the summer, 1976.

Copepoda

Copepods were represented by the harpacticoid *Attheyella nordenskioldii* (Lilljeborg), the cyclopoid *Cyclops vernalis* Fisher and the calanoid *Diaptomus leptopus* Forbes. All three species have a wide distribution throughout North America.

The single occurrence, 9 September 1975, of *D. leptopus*, a lentic species, is undoubtedly accidental. It is found in ponds and lakes at all altitudes in the Rocky Mountains (Ward and Wipple 1959) and was probably ferried to Cadomin Spring by waterfowl. A less likely possibility is that there is a communication between the cave system and a lake or pond, where *Diaptomus* normally occurs.

Both *A. nordenskioldii* and *C. vernalis* were common community members. *Attheyella* was found in all samples, and *Cyclops* was found in 14 of 16 samples at site A and 16 of 19 samples at site B. However, *A. nordenskioldii* specimens represented 12.7% and 8.8% of the total fauna from sites A and B respectively, while *C. vernalis* specimens represented less than 1% at both sites (Fig. 14).

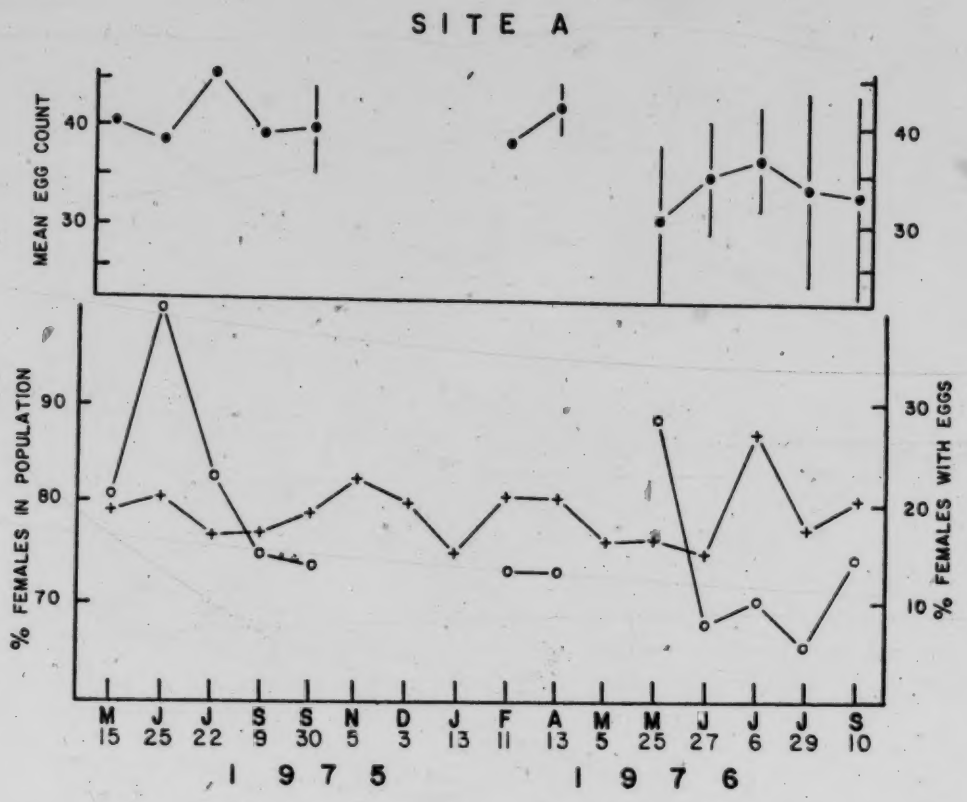
Of all taxa present in Cadomin Spring, *Attheyella* maintained

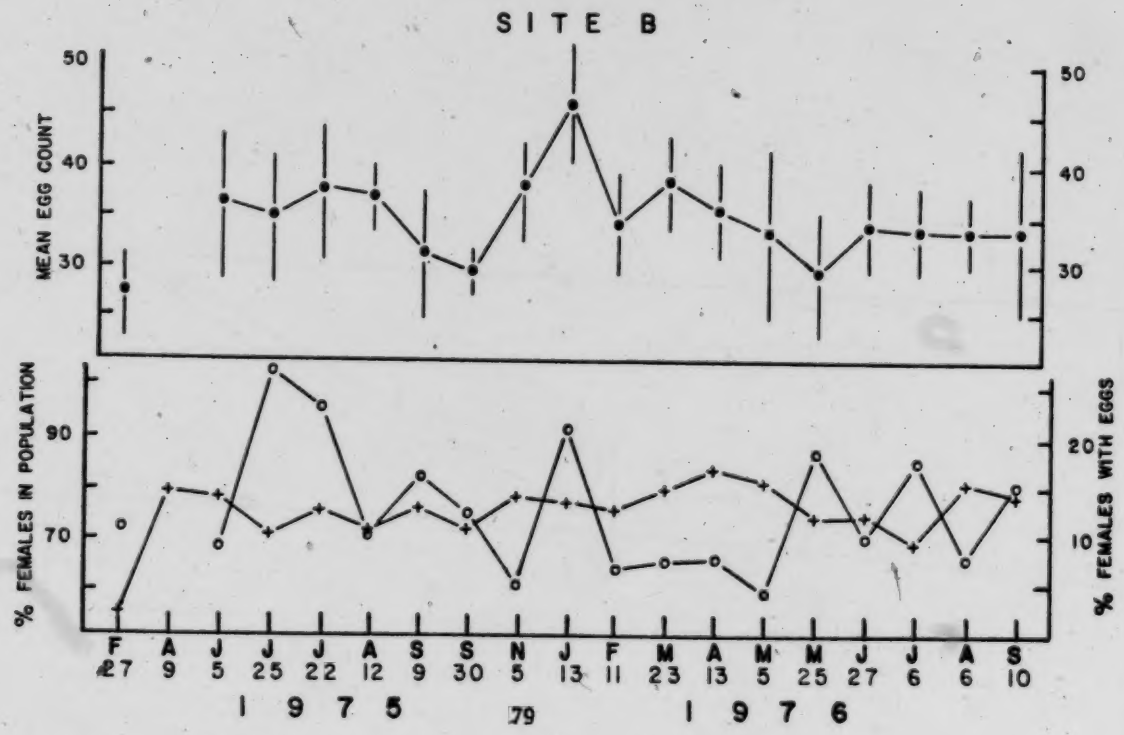
the most uniform relative abundance throughout the year. This consistency is of particular interest because it would indicate that these copepods are unaffected by the changing physical or chemical conditions of Cadomin Spring. Smyly (1961) found that *Cyclops leucharti* was confined to the epilimnion of a lake during summer thermostratification and suggested any animal descending into the hypolimnion would perish because of lack of oxygen. My results from Cadomin Spring suggest that the copepods, particularly *Attheyella*, can withstand wide fluctuations in dissolved oxygen levels;and, although low dissolved oxygen in winter appears to affect breeding activity (to be discussed later), the low level did not appear to affect the temporal distribution of these copepods.

I could not determine the complete life history of *Attheyella* because my dipnet's mesh size (420 microns) was too large to catch the nauplii or copepodid stages. However, I could determine: 1) adult sex ratios, 2) percent females with eggs, and 3) mean egg counts. Since there is very little ecological information available for harpacticoids, except for a few comments in systematic monographs (e.g. Borutskii 1952, Wilson 1956), much of my discussion will of necessity have to be based on lentic cyclopoids and calanoids and their associated life histories.

Both the A. *nordenskioldii* and C. *vernalis* populations were skewed in favor of females (Figs. 30 & 31). *Attheyella* populations had a total mean sex ratio of 78.9% $\pm$ 3.1% females at site A, with a range of 75.9% - 86.8%. At site B the total mean sex ratio was 74.4% $\pm$ 6.2% females, with all values but one ranging between 70.4%

Figure 30 Seasonal population parameters for Attheyella nordenskioldi. Vertical lines in the 'Mean Egg Count' graphs represent standard deviation.
+ —— + represents % females in population.
o —— o represents % females with eggs.


SITE A
MEAN EGG COUNT
40
30
% FEMALES IN POPULATION
90
80
70
% FEMALES WITH EGGS
30
20
10
M 15
J 25
J 22
S 9
S 30
N 5
D 3
J 13
F 11
A 13
M 5
M 25
J 27
J 6
J 29
S 10
1 9 7 5
1 9 7 6


SITE B
MEAN EGG COUNT
50
40
30
% FEMALES IN POPULATION
90
70
% FEMALES WITH EGGS
20
10
F 27
A 9
J 5
J 25
J 22
A 12
S 9
S 30
N 5
J 13
F 11
M 23
A 13
M 5
M 25
J 27
J 6
A 6
S 10
1 9 7 5
1 9 7 6

S I T E A
% FEMALES IN POPULATION
90
80
70
60
% FEMALES WITH EGGS
40
30
20
10
M J J S S N D J F A M M J J J S
15 25 22 9 30 5 3 13 11 13 5 25 27 6 29 10
1 9 7 5
1 9 7 6

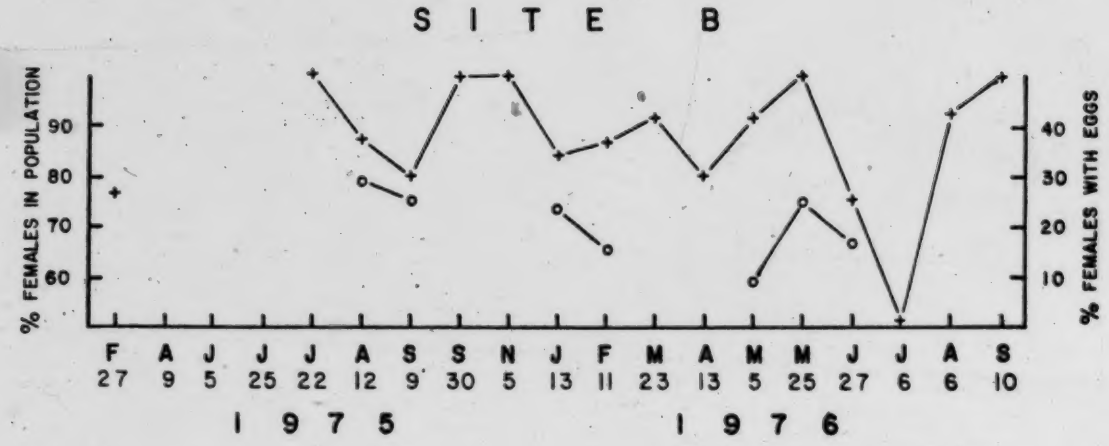

S I T E B
% FEMALES IN POPULATION
90
80
70
60
% FEMALES WITH EGGS
40
30
20
10
F A J J J A S S N J F M A M M J J A S
27 9 5 25 22 12 9 30 5 13 11 23 13 5 25 27 6 6 10
1 9 7 5
1 9 7 6

Figure 31 Seasonal population parameters for Cyclops vernalis.
+ —— + represents % females in population.
o —— o represents % females with eggs.

- 82.8%. Only once, 28 February 1975, did the sex ratio approach 1:1(54.2%). *Cyclops's* sex ratio was much more variable, with female percentages of 80.2% $\pm$ 25.1% (site A) and 79.8% $\pm$ 23.6% (site B) with a range of up to 100% females at each site. The sex ratio variability in C. *vernalis* is, in part, due to low numbers taken.

Female dominance can be a result of low population densities (Ravera 1955), sexes not being produced in a 1:1 ratio (Smyly 1961), or selective predation caused by sexual dimorphism or behavioral characteristics or both. The more numerous females, particularly in *Attheyella*, would appear to be most readily explained by the sexes not being produced in a 1:1 ratio. If population densities were important, one would expect male dominance at least sometime during the study. Predation on copepods undoubtedly took place; however, I was not able to determine whether predator selection for males occurred.

The proportion of egg-bearing *Attheyella* females ranged from 0-40% at site A and 0-26% at site B. This is much lower than the 0-93% range reported for *Diaptomus gracilis* (Smyly 1968), and the 65%-80% range for *Cyclops strenuus strenuus* (Elbourn 1966). I suspect that I underestimated the number of gravid females in the population, because there were numerous unattached egg clusters in my samples; these eggs would have become detached from the female during sampling.

The maximum proportion of egg-bearing females (suggesting maximum breeding activity) occurred in late spring and early summer

when dissolved oxygen and nutrient levels, resulting from the spring runoff, were high (Fig. 30). In contrast, the smallest percentage of gravid females (in some cases no gravid females at site A) occurred in winter when dissolved oxygen and nutrient levels were very low. Food shortages have been shown to inhibit breeding (Smyly 1973). In Cadomin Spring, I suspect that winter conditions reduced the quantity and perhaps quality of available food, in turn reducing *Attheyella's* breeding activity. While food conditions may contribute to reduced numbers of gravid females, the absence or presence of egg-bearing females at site A appear contingent upon dissolved oxygen. The absence of gravid females (end of September 1975 - January 1976) occurred when dissolved oxygen levels were very low. However, gravid females reappeared on 11 February 1976, concomitant with an increase in dissolved oxygen. Since aeration between sites A and B resulted in dissolved oxygen levels always higher at site B (Table 2), oxygen would not appear to be a factor at site B. I have no explanation for the sudden appearance of relatively large numbers of egg-bearing females in January 1976 at site B.

There was a tendency for the mean egg counts for A. *nordenskioldii* based on five mature egg sacs) to be inversely related to the egg-bearing females precentages (Fig. 30). A well defined annual life-cycle appeared to exist at site B, where minimum mean egg counts were observed in late fall and late spring with a sharp midwinter peak in between. During the remainder of the year, mean egg counts were relatively constant being midway between the maximum and minimum values. Mean egg counts at site A were similar to site B.

Increased mean egg counts have been associated with large, older females (Smyly 1968) and have been used to determine the age of the population (Ravera 1955). From the mean egg count data of *Attheyella*, therefore, I would predict the greatest proportion of older specimens occurring in mid-winter. This conclusion is supported by mean individual weight data, which also exhibited a peak during mid-winter and, particularly at site B, remained relatively uniform throughout the remainder of the year (Fig. 32).

*Cyclops vernalis* specimens occurred sporadically and in low numbers throughout the study, although they were more common in 1976 than 1975. Data on mean egg counts for *Cyclops* were not extensively analysed because few egg-bearing females were found, and those I did obtain indicated that egg-bearing females were most numerous in winter.

Isopoda

One species of isopod, *Salmasellus steganothrix* Bowman 1974 (Asellidae) occurs in Cadomin Spring. Its presence was sporadic and, being a blind hypogean isopod, it undoubtedly is found mainly in the deeper recesses of the cave Spring. This is the only known aquatic isopod from Alberta and the only known hypogean isopod from Canada. It represents an extraordinary range extension of North American hypogean isopods. The significance of its discovery will be discussed later when comments will be made on Cadomin Spring as a possible Wisconsin refugium.

Specimens were found only between May and September inclusive

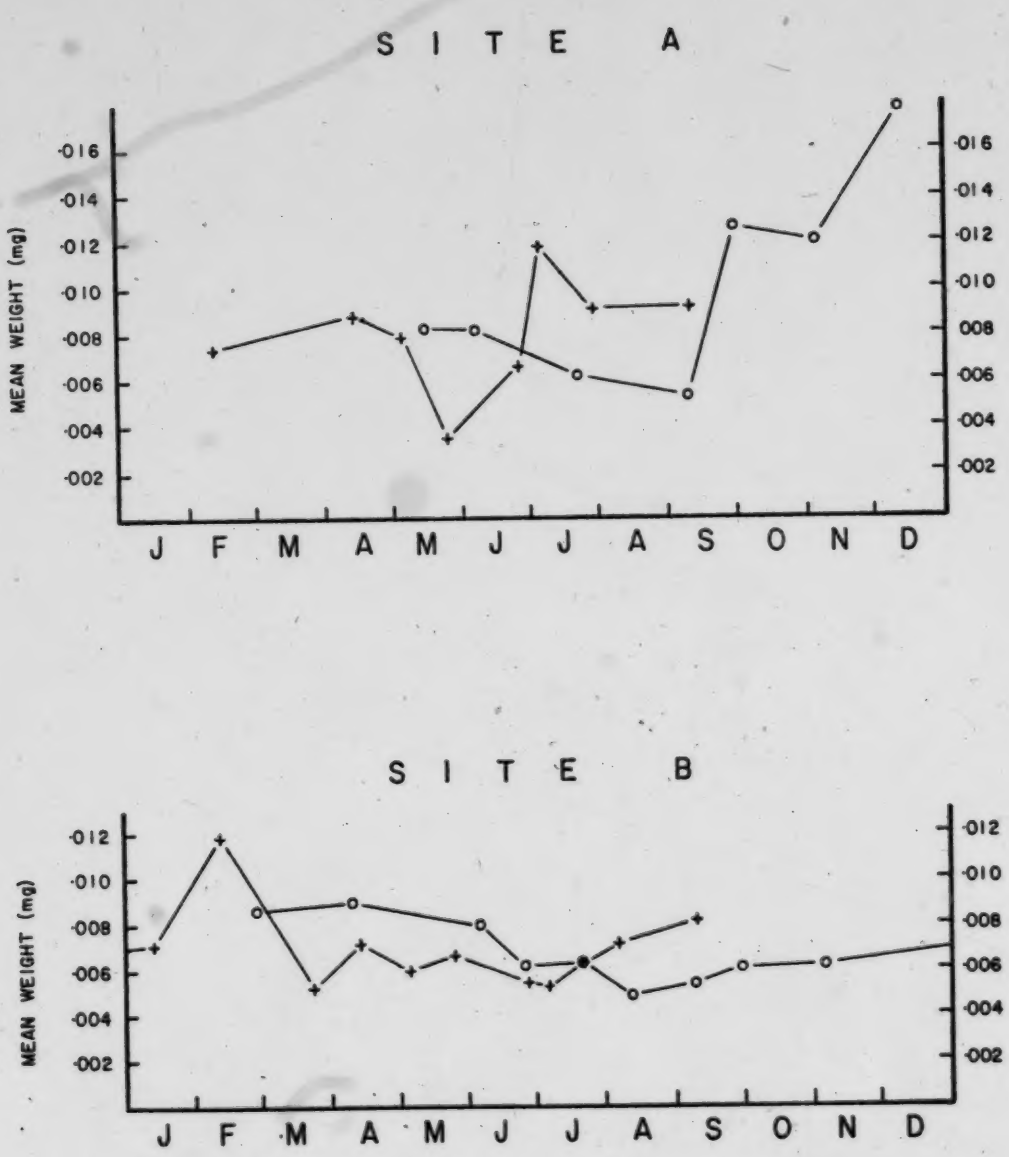



Figure 32. Mean individual weight profile for Attheyella nordenskioldi. o = 1975 data, + = 1976 data.

(Table 6). In May of both 1975 and 1976, the isopods were small (2-3 mm). Males with well differentiated pleopod genitalia (total length: 6.0 - 9.5 mm) were found in June, July and September 1975, most being collected on 22 July from the underside of a large flat stone near the source. On 10 September in the same area I collected one immature specimen and one ovigerous female (7.1 mm).

Despite a concerted effort, no isopods were hand picked from rocks in 1976, although they were periodically found in the regular samples, the smaller ones (2-3 mm) in spring and the larger ones (4-6 mm) in summer. Since the 1976 summer flow in Cadomin Spring was much higher than the summer flow of 1975, it is possible that most of the isopods were carried out of Cadomin Spring into the McLeod River. I never collected mature specimens in my regular samples of 1976.

While the data are scanty, they could indicate a possible annual cycle, reproduction occurring during the summer with the old generation dying out by midwinter.

Other Taxa

Two ostracod genera, *Prioncypris* and *Candona*, were identified. These crustaceans occurred in all seasons but never in large numbers (Figs. 15 & 16). Their presence throughout the year at both sites would indicate that they are unaffected by the changing chemical and physical conditions of the Spring. Overall, they represented 1.6% and 0.8% of the fauna by numbers from sites A and B respectively.

Water mites (Hydracarina) were occasionally present at both sites, but they occurred in very low numbers. No attempts were made

Table 6. Number of Salmasellus steganothrix in Cadomin Spring

| Date | Site A | Site B |
|---|---|---|
| 1975 | | |
| 15 May | 1 | - |
| 5 June | - | 1 |
| 25 June | 1 | - |
| 22 July | *10 | - |
| 9 September | * 2 | - |
| 1976 | | |
| 5 May | 1 | - |
| 25 May | 1 | 6 |
| 27 June | - | 1 |
| 6 July | 2 | - |
| 6 August | - | 1 |
| TOTAL | 18 | 9 |

*hand collected from rock near source

to identify the Nematoda. The tardigrade *Hypsibius* was infrequently collected.

# GENERAL DISCUSSION

## The Cadomin Spring Community

The fauna in Cadomin Spring suggested an impoverished community, both sites sampled being dominated by Chironomidae (36.1%) and Oligochaeta (46.6%). Noticeably absent were Amphipoda, Coleoptera, Hirudinea, Sphaeriidae, Plecoptera, Porifera, Gastropoda, Bivalvia and Hemiptera, animals Pennak (1953) described as typical components of cold spring faunas. Also, with the possible exception of the flatworm *Polycelis coronata* and some chironomids, there were few, if any, known stenotherms. Most of the animals that were dominant or consistently found year-round, e.g. Copepods and Oligochaeta, were taxa generally found in a variety of lentic and lotic systems. The lack of cold stenotherms seemed unusual because the temperature in the Spring never exceeded 8°C. A comparison of the major taxa of Cadomin Spring with that of a nearby pristine mountain stream, Jarvis Creek (Fig. 33) (Bergstrom and Jablonski 1977) shows how much the Spring was being affected. Three major groups, Ephemeroptera, Plecoptera and Trichoptera, often considered indicators of good water, were unable to complete their life cycles in Cadomin Spring, while in the mountain stream they were the dominant group. Hynes (1970) has suggested that either consistently low water temperatures or low dissolved oxygen concentrations can be limiting factors while Davidson and Wilding (1943) have shown food availability to be important. Undoubtedly, low temperatures, periodic low dissolved oxygen concentrations as well as reduction in both food quantity

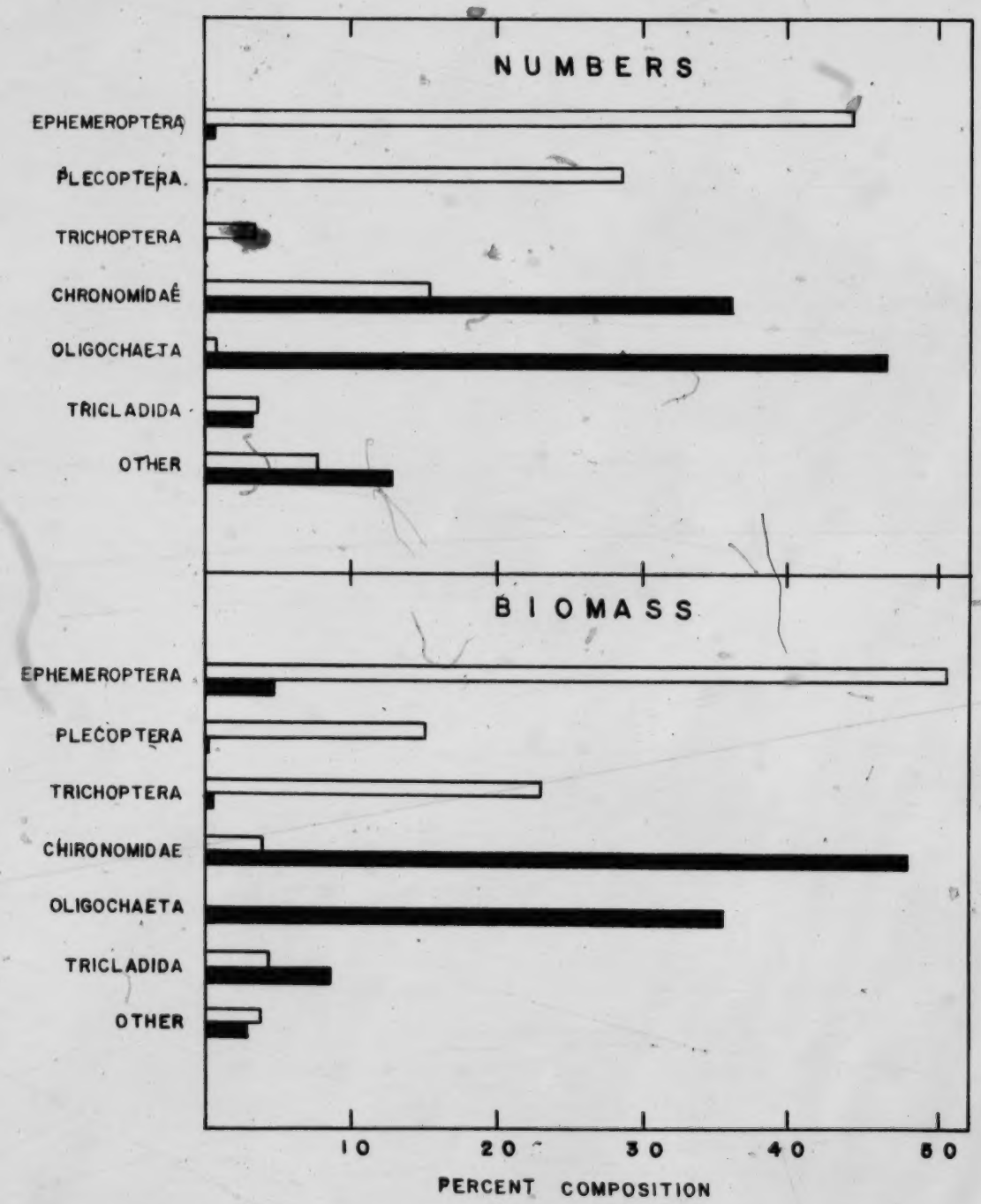



Figure 33 A comparison of the major invertebrate taxonomic groups of Cadomin Spring (■) and a nearby pristine mountain stream (□), Jarvis Creek.

and quality contributed to the Spring's condition. Lehmkuhl (1979), in discussing environmental disturbances and life histories, noted that even changes of two or three degrees during a critical period in the life history of an organism can preclude hatching, molting or emergence; thus eventually wiping out the species. This could be one important reason for the lack of success of insects, except for Chironomidae, in populating Cadomin Spring.

However, Cadomin Spring's dissolved oxygen concentrations, at least superficially, appear to be the most important variable. During winter, when baseflow primarily made up the streamflow, dissolved oxygen concentrations at the source fell to undetectable levels. As the water moved down the surface channel, aeration occurred so that by the time the water reached site B it had sustained enough oxygen to influence a community twice as diverse as that at site A. During the spring and summer, when dissolved oxygen concentrations usually rose significantly (due to the contribution of water from snowmelt and summer storms) the diversity at both sites, particularly site A, increased. This resulted in the diversity difference between sites A and B becoming much smaller. Studies from other springs where dissolved oxygen concentrations during all seasons were consistently higher than those of Cadomin Spring indicate much richer faunal communities (Nielson 1950, Stern & Stern 1969, Davidson and Wilding 1943). As noted earlier, in Cadomin Spring, dissolved oxygen concentrations were directly dependent upon either snow-melt or summer storms. Because of this, wide and

rapid fluctuations sometimes occurred even during summer with concentrations dropping to less than 1 mg/1 during prolonged dry periods and rising rapidly to greater than 8 mg/1 during heavy rainstorms. Thus, even during summer, the fauna was periodically subjected to the harsh conditions it faced during the winter. This was particularly evident in summer 1975 which, compared to summer 1976, received fewer summer storms, resulting in lower minimum dissolved oxygen readings and subsequently a lower faunal diversity.

One interesting note regarding dissolved oxygen concentrations and its effect on the aquatic community occurred on 11 February 1976. The reading prior to this date (11 January 1976) was less than 1 mg/1 at the source. However, on 11 February for some unexplained reason the dissolved oxygen concentration exceeded 3 mg/1. Small mayfly nymphs, egg-bearing female copepods and oligochaete cocoons were concomitantly found in the benthic sample taken at the time. At site B, little change occurred in the benthos, because this site never experienced the same low oxygen concentration readings as site A. By 22 March, the dissolved oxygen concentration had once again dropped to below 1 mg/1 at site A. The benthic sample taken at this time from site A revealed no egg-bearing female copepods, no mayfly nymphs, and no oligochaete cocoons; and these did not reappear until the commencement of spring when snowmelt increased dissolved oxygen levels.

Because of this "harsh" environment, most of the aquatic insects could not complete their life cycle in Cadomin Spring.

Exceptions were some chironomids, one trichopteran (*Ecclisomyia conspersa*) and perhaps some of the Tipulidae. Nymphs of the two *Ameletus* species migrated from the McLeod River into Cadomin Spring, where they emerged and at least some of the female imagoes oviposited in the Spring, but the new generation apparently did not survive the winter. All other insects were represented by only sporadic appearances and therefore are considered adventitious occurrences, either through migration from the McLeod River or hatching from eggs laid by indiscriminate females.

The changes in water temperature of Cadomin Spring were also directly controlled by the snow-melt and summer storms runoff. During winter, when the only contribution to the Spring was baseflow, the water temperature was steady at about 7°C. As water contribution from snow-melt and summer storms entered the cave system, water temperature dropped to about 4°C and then gradually increased again as baseflow contribution to the overall streamflow increased. Thus, in a sense the fauna of Cadomin Spring was experiencing "winter" conditions during the summer season and "summer" conditions during winter.

The large springs of Denmark (Nielson 1950) and springs in northern England (Ford and Cullingford 1976) showed similar water temperatures to that of the baseflow in Cadomin Spring. In both Denmark and England, the water temperatures were attributed to the mean annual air temperatures of their respective regions. In the Cadomin area, the mean annual air temperature of -0.1°C would therefore not account for the 7°C baseflow water temperature. Thus,

one might suspect that either the baseflow is being affected by a much larger region than the local area or the Spring has a deep water source (Pennak 1953, Ford and Cullingford 1976). The most plausible explanation would seem to be a deep water source as Cadomin Spring is located on or very close to a fault line from which the water could be coming.

While the system is somewhat faunistically impoverished, its simplicity, relative constancy, and open water year-round makes it an ideal natural outdoor laboratory. Considering the gap that often exists between laboratory and field data, often precluding extrapolation from one to the other, future work in Cadomin Spring under the relatively "controlled" conditions could be most rewarding.

Evidence for a Glacial Refugium

At the height of Wisconsin glaciation, Alberta, except for the Cypress Hills in the extreme southeastern corner and the Porcupine Hills in the southwest, has been portrayed as being inundated by Cordilleran (from the west) and Laurentide (from the east) ice (Atlas of Alberta 1969). The Cadomin area would have been situated in the area of the coalescence of the two ice masses. However, geological evidence is now accumulating that suggests the great ice masses advanced and receded at least two or three times in a non-synchronous manner, so that coalescence seldom occurred. In southern Alberta, synchrony is thought to have never occurred (Alley 1973), while in west-central Alberta, Roed (1968) found evidence for only one coalescence of Cordilleran and Laurentide ice. This coalescence was restricted to the Athabasca Valley, which is situated

northeast of the Cadomin area. Reeves (1973), after reviewing all the pertinent data on the nature of the contact between the Cordilleran and Laurentide ice masses, concluded that the only incontrovertible evidence for coalescence occurred in the Athabasca Valley, probably in early Wisconsin time. The only other coalescence was probably a few piedmont lobes making contact with Laurentide ice. However, as this would be only for relatively short times and would cover relatively short distances, there would be an ice-free corridor or at least large ice-free areas for most of Wisconsin time. Stalker (1977) puts the maximum extension of the Laurentide ice well east of the Cadomin area and hence it is unlikely it would have had much influence on the area. Even during the greatest Cordilleran advances in early Wisconsin time, the higher mountain areas probably stood as nunataks above the ice (Williams and Bayrock 1966).

Packer and Vitt (1974) give substantial evidence of a plant refugium in the Mountain Park area, 6 km south of Cadomin Spring. Their evidence comes from disjunct populations of alpine and montane bryophytes and angiosperms. Although their refugium is at high elevations, they were convinced that many lowland areas were also open, particularly in the mid-Wisconsin time.

Cadomin Spring would appear to furnish the first actual zoological evidence to support the hypothesis of this area as a refugium. Two animals, *Salmasellus steganothrix*, the blind hypogean isopod, and *Rhynchelmis elrodi*, a lumbriculid oligochaete, represent a disjunct group and a disjunct species, respectively. From the

extension of the range of *R. elrodi*, a non-vagile animal, it is difficult to conceive of a slow migration into the area following the final recession of the glaciers. Since *S. steganothrix* is a new genus with no closely affiliated species (Bowman 1975), it is conceivable that it occurred in the western Canadian region prior to Wisconsin glaciation. Perhaps glaciation destroyed most of the other areas where the isopods were found; but, as the Cadomin area was left unglaciated or perhaps only covered for relatively short periods, Cadomin Spring acted as a refugium.

Thus, there is good zoological evidence from my study for a refugium in the Cadomin area.

## LITERATURE CITED

ALLEY, N.F. 1973. Glacial stratigraphy and the limits of the Rocky Mountain and Laurentide ice sheets in southwestern Alberta, Canada. Bull. Can. Petr. Geol. 21(2): 153-177.

ASTON, R.J. 1973. Tubificids and water quality: A review. Environ. Pollut. 5:1-10.

ATLAS OF ALBERTA. 1969. Government of Alberta and University of Alberta, Edmonton. University of Alberta Press, Edmonton and Toronto. 168 pp.

BERGSTROM, Glen and Paul JABLONSKI. 1977. Luscar Water Quality Study. Dept. of Energy and Natural Res., Forest Land Use Branch, Watershed Management Section. Unpublished in-house report. 85 pp.

BERKOWITZ, N. 1969. On the probable environmental effects of coal mining and combustion in western Canada. Res. Coun. of Alta., Edmonton. Cont. No. 449. 12 pp.

BORUTSKII, E.V. 1952. Fauna of the USSR: Freshwater Harpacticoida. Halsted Press-- A division of John Wiley & Sons, New York. 408 pp. Translated in 1964.

BOWMAN, T.E. 1974. The California freshwater isopod, *Asellus tomalenis*, rediscovered and compared with *Asellus occidentalis*, Hydrobiologia, 44: 431-441.

_____. 1975. Three new troglobitic Asellids from western North America (Crustacea: Isopoda: Asellidae). Int. J. Speleol. 7: 339-356.

BRINKHURST, R.O. 1966. The Tubificidae (Oligochaeta) of polluted waters. Verh. Int. Verein. Limnol. 16: 854-859.

BRINKHURST, R.O. 1978. Freshwater Oligochaeta in Canada. Can. J. Zool. 56: 2166-2175.

BRINKHURST, R.O. and B.G.M. JAMIESON. 1971. Aquatic Oligochaeta of the World. Oliver & Boyd, Edinburgh. 860 pp.

CLIFFORD, Hugh F. 1969. Limnological features of a northern brown-water stream, with special reference to the life histories of the aquatic insects. Am. Mid. Nat. 82: 578-597.

CLIFFORD, Hugh F. and Glen BERGSTROM. 1976. The blind aquatic isopod *Salmasellus* from a cave spring of the Rocky Mountains' eastern slopes, with comments on a Wisconsin refugium. Can. J. Zool. 54(11): 2028-2032.

DAVIDSON, F.A. and J.L. WILDING. 1943. A quantitative faunal investigation of a cold spring community. Am Midl. Nat. 29: 200-209.

DAVIS, Ron. 1972. A preliminary study of water quality in the Luscar coal area, Alberta. M. Sc. thesis, Col. State Univ., Ft. Collins, Colorado. 89 pp.

DUMANSKI, J; T.M. MACYK; C.F. VEAUVY; and J.D. LINDSAY. 1972. Soil Survey and Land Evaluation of the Hinton-Edson Area, Alberta. Alberta Institute of Pedology, Report #5-72-31. Research Council of Alberta, Report #31. 119 pp.

ELBOURN, C.A. 1966. The life cycle of *Cyclops strenuus strenuus* Fischer in a small pond. J. Anim. Ecol. 35: 333-347.

FOLSOM, Todd C. 1976. Ecology of *Dugesia tigrina* in Lake Wabamum. M. Sc. Thesis, University of Alberta, Dept. of Zoology, 89 pp.

FORD, T.D. and C.H.D. CULLINGFORD (Ed.). 1976. The Science of Speleology Academic Press, London, New York, San Francisco. 593 pp.

GOTTS, R.J. 1966. The Cadomin limestone quarry. *In* Guidebook of the Eighth Annual Field Trip to Cadomin Alberta. (Ed. G.D. Williams). 134 pp.

GUY, Harold P. 1969. Laboratory theory and methods for sediment ananlysis. Techniques of Water-Resources Investigations of the United States Geological Survey. U.S. Dept. of the Interior.

HALLADAY, I.R. 1966. Some aspects of the natural history of the Cadomin area. *In* Edmonton Geological Society Guidebook: Eighth Annual Field Trip to Cadomin, Alberta. (ed. G.D. Williams). 134 pp.

HULTIN, Lennart; Bo SVENSSON; and Staffan ULFSTRAND. 1969. Upstream movements of insects in a South Swedish small stream. Oikos 20(2): 553-557.

HYMAN, L.H. 1931. Studies on the morphology, taxomony, and distribution of North American Triclad Turbellaria. III On *Polycelis coronata* (Girard). Trans. Am. Micro. Soc. 50: 124-135.

HYNES, H.B.N. 1958. The effect of drought on the fauna of a small mountain stream in Wales. Verh. internat. Ver. Limnol. 13: 826-833.

_____. 1961. The invertebrate fauna of a Welsh mountain stream. Arch. Hydrobiol. 57: 344-388.

_____. 1970. The Ecology of Running Water. University of Toronto Press, Toronto. 555 pp.

IVERSON, Torben Moth. 1976. Life cycle and growth of Trichoptera in a Danish spring. Arch. Hydrobiol. 78(4): 482-493.

JABLONSKI, Paul D. 1978. Mesoclimate of the Tri-Creeks region. Alberta Energy and Natural Resources, Forest Land Use Branch, Watershed Management Section. Report #3. 19 pp.

JEFFERSON, G.T. 1976. Cave faunas. In The Science of Speleology, T.D. Ford and C.H.D. Cullingford. (Ed.) 593 pp.

KENNEDY, C.R. 1966. The life history of *Limnodrilus hoffmeisteri* Clap. (Oligochaeta: Tubibicidae) and its adaptive significance. Oikos 17: 158-168.

LADLE, M. 1971. Studies on the biology of oligochaetes from the phreatic water of an exposed gravel bed. Internat. J. Speleol. 3: 311-316.

LEHMKUHL, D.M. 1979. Environmental disturbance and life history: principles and examples. J. Fish. Res. Bd. Can. 36: 329-334.

LINDEGAARD, Claus and Jens THORUP. 1975. The invertebrate fauna of the moss carpet in Danish spring Ravnkilda and its seasonal, vertical, and horizontal distribution. Arch. Hydrobiol. 75(1): 109-139.

MARSHALL, J.W. 1973. A benthic study of the Avon Spring stream, Christchurch. Mauri Ora, 1: 79-90.

MASON, William T., Jr. 1973. An Introduction to the Identification of Chironomid Larvae. Analytical Quality Control Laboratory, National Environmental Research Center, U.S. Environmental Protection Agency. 90 pp.

McKEE, J.E. and H.W. WOLF. 1963. Water Quality Criteria, 2nd Edition. The Resource Agency of California. State Water Quality Control Board.

MERRITT, R.W. and K.W. CUMMINS. 1978. An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing Co. 441 pp.

MINCKLEY, W.L. 1963. The ecology of a spring stream: Doe Run, Meade County, Kentucky. Wildlife Monogr., 11: 1-124.

MINSHALL, G. Wayne. 1968. Community dynamics of the benthic fauna in a woodland spring brook. Hydrobiologia, 32: 305-339.

MOUNTJOY, E.W. 1962. Mount Robson (Southeast) Map-area. Rocky Mountains of Alberta and British Columbia. Geol. Surv. Can., Pap. 31-61, 114 pp.

NAGELL, Bjorn. 1973. The oxygen consumption of mayfly (Ephemeroptera) and stonefly (Plecoptera) larvae at different oxygen concentrations. Hydrobiologia 42 (4): 461-489.

NATIONAL ATLAS OF CANADA. 1975. Dept. of Mines and Tech. Surveys, Geographical Branch, Ottawa. 254 pp.

NEEDHAM, J.G., J.R. TRAVER, and Y. HSU. 1935. The Biology of Mayflies. 759 pp. Ithaca, N.Y.

NIELSEN, Anker. 1950. On the zoogeography of springs. Hydrobiologia 2: 313-320.

NIMMO, A.P. 1971. The adult Rhyacophilidae and Limnephilidae (Trichoptera) of Alberta and eastern British Columbia and their post-glacial origin. Quaest. Ent. 7: 3-234.

NOEL, M.S. 1954. The animal ecology of a New Mexico springbrook. Hydrobiologia, 6: 120-135.

ODUM, H.T. 1957. Trophic structure and productivity of Silver Springs, Florida. Ecol. Monogr., 27: 55-112.

OLIVER, D.A. 1971. Life history of the Chironomidae. Ann. Rev. Ent. 16: 211-230.

PACKER, John G. and Dale H. Vitt. 1974. Mountain Park: a plant refugium in the Canadian Rocky Mountains. Can. J. Bot. 52 (6): 1393-1409.

PENNAK, Robert W. 1953. Fresh-Water Invertebrates of the United States. The Ronald Press Co., New York. 769 pp.

RAVERA, Oscar. 1955. Seasonal variation of the reproductive rate in pelagic copepods of Lake Maggiore. Verh. Internat. ver. Limnol. 12: 436-446.

REEVES, B.O.K. 1973. The nature and age of the contact between the Laurentide and Cordilleran ice sheets in the western interior of North America. Arctic and Alpine Research, 5 (1): 1-16.

ROED, Murray A. 1974. Cordilleran and Laurentide multiple glaciation west-central Alberta, Canada. Can. J. Earth Sci., 12: 1493-1515.

ROWE, J.S. 1959. Forest regions of Canada. Can. Dept. of Nor. Aff. and Nat. Res., Forest Branch, Ottawa, Bull. #123.

SALT, Ray W. and Jim R. SALT. 1976. The Birds of Alberta. Hurtig Publishers, Edmonton. 498 pp.

SMYLY, W.J.P. 1961. The life cycle of the freshwater copopod *Cyclops leuckarti* Claus in Esthwaite Water. J. Anim. Ecol. 30: 153-169.

_____. 1968. Number of eggs and body-size in the freshwater copepod *Diaptomus gracilis* Sars in the English Lake District. Oikos 19: 323-338.

_____. 1973. Clutch-size in the freshwater cyclopoid copepod, *Cyclops strenuus abyssorum* Sars in relation to thoracic volume and food. J. Nat. Hist. 7: 545-549.

SOPER, Dewey J. 1964. The Mammals of Alberta. The Hamly Press Ltd. Edmonton, Alberta. 408 pp.

STALKER, A. Mac S. 1977. The probable extent of Classical Wisconsin ice in southern and central Alberta. Can. J. Earth Sci. 14: 2614-2619.

STERN, Michele S. and Danial H. STERN. 1969. A Limnological study of a Tennessee cold springbrook. Am. Midl. Nat. 82 (1): 62-82.

STEVENSON, John. 1930. The Oligochaeta. Oxford, Clarendon. 978 pp.

TEAL, J. M. 1957. Community metabolism in a temperate cold spring. Ecol. Monogr. 27: 283-302.

ULFSTRAND, S. 1968. Benthic animal communities in bottom organisms. Oikos Suppl. 10: 120 pp.

USINGER, Robert L. 1963. Aquatic Insects of California. Univ. Calif. Press, Berkeley and Los Angeles. 508 pp.

WARD, Henry B. and George C. WHIPPLE. 1959. Fresh Water Biology (Ed. W. T. Edmondson). John Wiley and Sons, Inc. 1248 pp.

WATERS, T. F. 1972. The drift of stream insects. Ann. Rev. Entomol. 17: 253-272.

WEISEL, George F. and Robert L. NEWELL. 1970. Quality and seasonal fluctuation of headwater streams in western Montana. Montana Forest and Conservation Experimental Station, School of Forestry, Univ. of Montana. Bull. #38. 15pp.

WETZEL, Robert G. 1975. Limnology. W.B. Saunders Co., Philadelphia, London, Toronto. 743 pp.

WIGGINS, Glenn B. 1978. Trichoptera : An Introduction to the Aquatic Insects of North Amer ca. Ed. by R. W. Merritt and K.W. Cummins. Kendall/Hunt Publ. Co. pp. 147-185.

WILLIAMS, G. D. (Ed.). 1966. Edmonton Geological Society Guidebook: Eighth Annual Field Trip to Cadomin, Alberta. 134 pp.

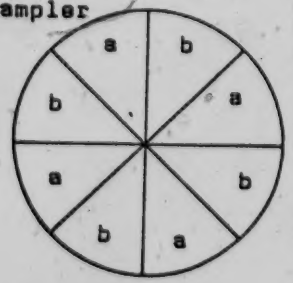
WILLIAMS, G. D. and L. A. BAYROCK. 1966. Surficial geology between Edmonton and Cadomin near highways 16 and 47. *In* Edmonton Geological Society Guidebook: Eighth Annual Field Trip to Cadomin, Alberta. (Ed. G. D. Williams). 134 pp.

WILSON, Mildred S. 1956. North America harpacticoid copepods. 1. Comments on the known fresh-water species of the Canthocamptidae. 2. *Canthocamptus oregonenis* (n.sp.) from Oregon and California. Trans. Amer. Micro. Soc. 75: 290-307.

APPENDIX 1. Subsampler check. A = total number for the respective major taxa in sections a*. B = total number for the respective major taxa in sections b.

| | 13 January | | | 11 February | | | 8 March | | | 13 April | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | % DIFF. | A | B | % DIFF. | A | B | % DIFF. | A | B | % DIFF. |
| Chironomidae | 1478 | 1340 | 4.88 | 156 | 146 | 3.32 | 2920 | 3336 | 6.64 | 1689 | 1582 | 3.28 |
| Oligochaeta | 1761 | 1778 | 0.08 | 2075 | 1959 | 2.88 | 1529 | 1756 | 6.92 | 1480 | 1327 | 5.44 |
| Copepoda | 139 | 128 | 4.18 | 337 | 326 | 1.66 | 335 | 383 | 6.68 | 502 | 452 | 5.24 |
| Ostracoda | **10 | 5 | | 117 | 120 | 1.26 | 39 | 39 | 0.00 | 80 | 61 | 13.46 |
| Tricladida | 7 | 5 | | | | | 197 | 208 | 2.72 | 396 | 387 | 1.14 |
| Ephemeroptera | 10 | 3 | | 0 | 2 | | | | | 1 | 0 | |
| Plecoptera | | | | | | | | | | 1 | 1 | |
| Trichoptera | 1 | 0 | | | | | 4 | 3 | | 1 | 5 | |
| Nematoda | | | | 4 | 4 | | 5 | 4 | | 46 | 41 | 5.74 |
| Hydracarina | | | | | | | 2 | 2 | | 4 | 3 | |
| Tipulidae | | | | | | | | | | | | |
| TOTAL | 3406 | 3259 | 2.20 | 2685 | 2557 | 2.44 | 5031 | 5731 | 6.52 | 4199 | 3858 | 4.24 |

* Top view of subsampler




** % differences not calculated for any taxon that totaled 20 organisms or less on any one sampling date.

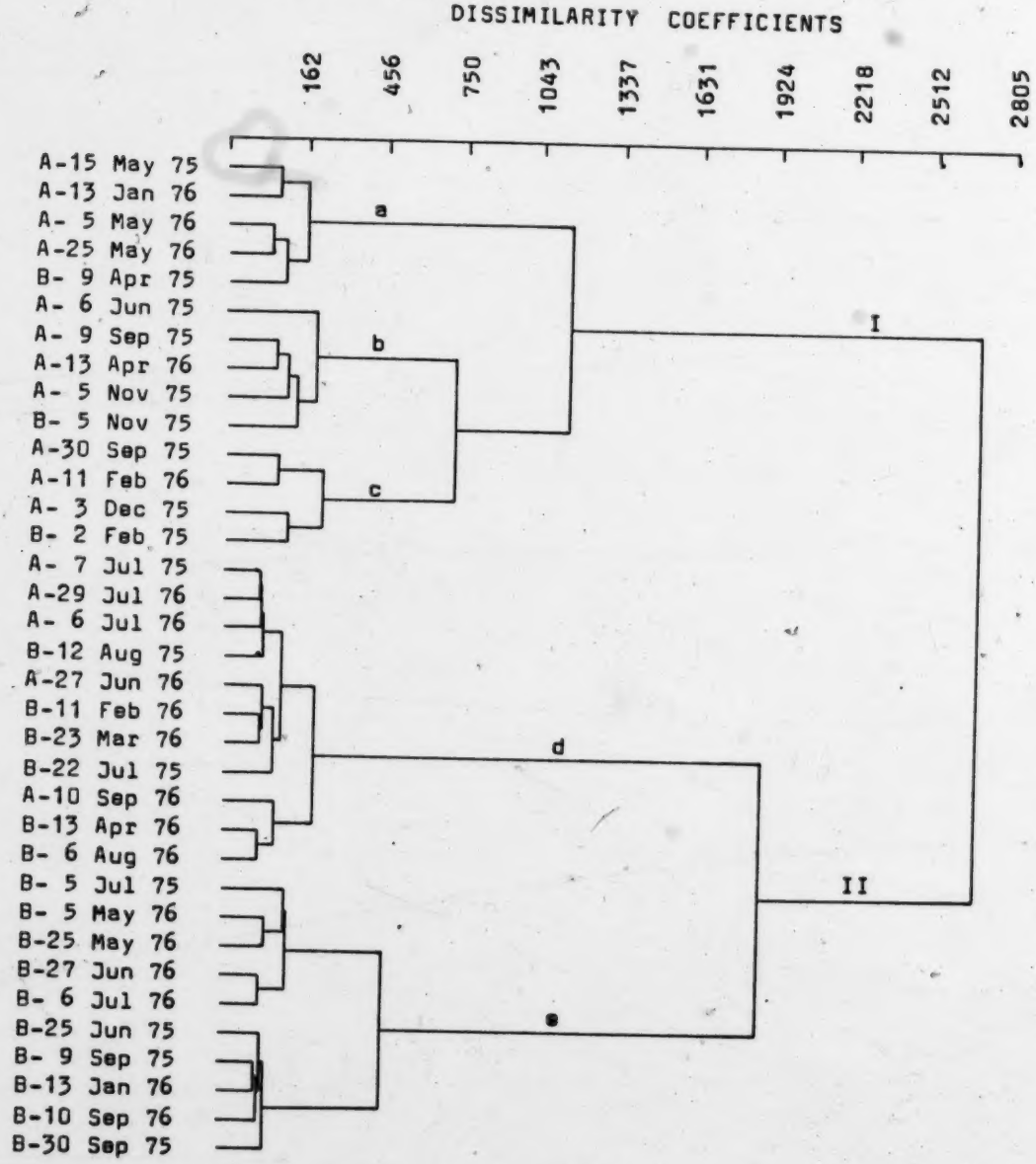
APPENDIX 2. Taxa found in Cadomin Spring. A = Abundant, C = Common, O = Occasional, R = Rare.

| | | |
|---|---|---|
| Nematoda | | |
| Platyhelminthes | | |
| Turbellaria | | |
| Tricladida | Polycelis coronata | C |
| Tardigrada | | |
| Eutardigrada | | |
| Macrobiotidae | Hypsibius sp. | O |
| Annelida | | |
| Oligochaeta | | |
| Naididae | Nais elinquis | A |
| | Chaetogaster sp. | O |
| Tubificidae | Limnodrilus hoffeisteri | C |
| Lumbriculidae | Rhynchelmis elrodi | C |
| Enchytraeidae | | A |
| Crustacea | | |
| Ostracoda | | C |
| Copepoda | | |
| Harpacticoida | Atthyella nordenskioldi | A |
| Cyclopoida | Cyclops vernalis | C |
| Calanoida | Diaptomus leptopus | R |
| Insecta | | |
| Collembola | | O |
| Ephemeroptera | Ameletus velox | C |
| | Ameletus celeroides | C |
| | Baetis sp. | O |
| | Cinygmula sp. | O |
| Plecoptera | | |
| Nemouridae | | |
| Leutrinae | | R |
| Capninae | Eucapnopsis sp. | R |
| Nemourinae | Nemoura (Zapada) sp. | O |
| Tanytarsinae | Branchyptera sp. | R |
| Perlodidae | Archynopteryx (Mergarcys) | R |
| | Alloperla sp. | O |
| Trichoptera | | |
| Rhyacophilidae | Rhyacophila spp. | R |
| Hydropsychidae | Parapsyche sp. | R |
| Limnopilidae | Ecclisomyia sp. | C |
| Hydracarina | | O |
| Diptera | | |
| Tipulidae | Pedicia sp. | R |
| | Antocha sp. | C |
| | Ormosia sp. | C |
| | Tipula sp. | R |

APPENDIX 2. Continued.

| | | |
|---|---|---|
| Diptera | | |
| Muscidae | *Limnophora* sp. | O |
| Empididae | *Chelifera* sp. | O |
| Ephydridae | | R |
| Psychodidae | | R |
| Ceratopogonidae | | R |
| Chironomidae | | |
| Diamesinae | *Diamesa* spp. | C |
| | *Pagastia partica* | A |
| | *Potthastia* or *Sympotthastia* | R |
| | *Pseudodiamesa* sp. | R |
| Orthocladinae | *Corynoneura* sp. | R |
| | *Cricotopus* - *Orthocladius* spp. | A |
| | *Eukiefferiella* spp. | O |
| | *Diplocladius* sp. | C |
| | *Heterotrissocladius* sp. | R |
| | *Hydrobaenus* sp. | R |
| | *Limnophyes* sp. | R |
| | *Rheocricotopus* sp. | R |
| | *Synorthocladius* sp. | R |
| | *Zalutshcia* sp. | R |
| Chironominae | *Micropsectra* spp. | O |
| | *Phaenopsectra* sp. | R |
| | *Polypedilum fallax* | R |
| Tanypodinae | *Macropelopia* sp. | R |
| | *Thenemannimyia* sp. | R |
| | *Zavrelimyia* sp. | R. |

APPENDIX 3. Dendrogram describing the similarity between the samples collected in Cadomin Spring. A = site A, B = site B. I and II represent primary clusters. a,b,and c are subclusters of I; d and e are subclusters of II.



APPENDIX 4. Temporal variations in the chemical constituents, 1975.

| | Alkalinity* (mg/l) | Calcium Hardness* (mg/l) | Total Hardness* (mg/l) | Total Phosphate (mg/l) | Ortho Phosphate (mg/l) | Organic Phosphate (mg/l) | Meta and Poly Phosphate (mg/l) | Nitrate Nitrogen (mg/l) | Organic Nitrogen (mg/l) | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| Jan. 3 | 99.3 | 130 | 224 | - | - | - | - | 0.02 | - | 7.84 |
| Feb. 27 | 120.7 | 144 | 236 | 0.07 | - | 0.07 | - | - | 0.07 | 7.94 |
| April 9 | 71.6 | 120 | 212 | 0.09 | - | 0.04 | 0.05 | - | - | 8.38 |
| May 15 | 87.7 | 83 | 130 | 0.13 | - | 0.08 | 0.05 | 0.12 | - | 7.91 |
| May 23 | 92.0 | 92 | 182 | 0.05 | - | - | 0.05 | 0.13 | 0.30 | 7.88 |
| May 29 | 79.9 | 81 | 124 | 0.29 | - | 0.29 | 0.05 | 0.13 | 0.04 | 8.22 |
| June 6 | 75.0 | 72 | 116 | 0.22 | - | 0.22 | - | 0.10 | 0.11 | 7.99 |
| June 12 | 88.5 | 91 | 144 | 0.16 | - | 0.10 | 0.06 | 0.08 | - | 7.93 |
| June 18 | 85.5 | 81 | 130 | 0.09 | - | 0.09 | - | 0.10 | 0.04 | 7.93 |
| June 25 | 67.6 | 63 | 107 | 0.12 | - | 0.04 | 0.08 | 0.07 | - | 8.13 |
| July 2 | 55.3 | 48 | 96 | 0.10 | - | 0.10 | 0.05 | 0.09 | - | 7.48 |
| July 9 | 55.6 | 43 | 108 | 0.12 | - | 0.06 | 0.06 | 0.02 | 0.02 | 8.04 |
| July 16 | 73.2 | 76 | 133 | 0.07 | - | 0.07 | - | 0.06 | 0.08 | 8.12 |
| July 23 | 98.3 | 129 | 178 | 0.18 | - | 0.18 | - | 0.08 | - | 8.12 |
| July 30 | 95.0 | 104 | 188 | 0.11 | - | - | 0.11 | 0.06 | 0.08 | 8.21 |
| Aug. 8 | 104.1 | 124 | 200 | 0.12 | - | - | 0.12 | 0.07 | - | 8.02 |
| Aug. 12 | 105.1 | 125 | 208 | 0.07 | - | 0.07 | - | 0.02 | 0.01 | 7.64 |
| Aug. 23 | 92.4 | 104 | 178 | 0.10 | - | - | - | 0.14 | - | 7.81 |
| Sept. 9 | 94.8 | 116 | 190 | 0.09 | 0.05 | 0.04 | - | 0.10 | - | 7.58 |
| Sept. 30 | 96.4 | 111 | 193 | 0.05 | - | - | - | 0.09 | - | 7.59 |
| Nov. 5 | 108.0 | 134 | 280 | 0.11 | - | 0.05 | 0.06 | 0.03 | - | 7.12 |
| Dec. 3 | 113.0 | 134 | 224 | 0.26 | - | 0.06 | 0.07 | 0.03 | 0.05 | 7.44 |

* as $CaCO_3$

APPENDIX 4. Continued

| | | Conductivity (micrpmhos) | Total Residue (mg/l) | Sulfate (mg/l) | Chloride (mg/l) | Color | Iron (mg/l) | Silica (mg/l) | Dissolved Oxygen (mg/l) | Dissolved Oxygen (% sat.) | Turbidity (J.T.U.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | 3 | 430 | 364 | 110 | 6.1 | 6 | 0.07 | 4.65 | 0.30 | - | 12 |
| Feb. | 27 | 428 | 299 | 114 | 1.4 | 6 | 0.08 | 4.85 | 0.22 | - | 3 |
| April | 9 | 380 | M | 140 | 8.4 | - | - | - | - | - | 10 |
| May | 15 | 200 | 70 | - | 1.4 | - | 0.06 | 2.55 | 6.18 | - | 5 |
| May | 23 | 200 | 294 | 39 | 2.7 | 25 | 0.10 | 3.00 | 6.28 | - | 5 |
| May | 29 | 75 | 38 | 27 | 2.8 | 3 | 0.06 | - | M | - | 8 |
| June | 6 | 103 | 52 | 27 | 2.8 | 6 | 0.12 | 0.11 | M | - | 11 |
| June | 12 | 220 | 132 | 40 | 3.3 | - | - | - | 7.36 | 67.2 | 6 |
| June | 18 | 180 | 115 | 19 | 2.1 | - | - | - | 0.48 | 88.8 | 7 |
| June | 25 | 195 | 199 | 42 | 3.7 | - | - | - | 7.69 | 74.4 | 14 |
| July | 2 | 144 | 251 | 17 | 0.8 | - | - | - | 9.44 | 82.8 | 17 |
| July | 9 | 187 | 167 | 41 | 4.5 | 3 | - | - | 6.32 | 60.6 | 15 |
| July | 16 | 251 | 188 | 65 | 5.7 | - | - | - | 4.95 | 46.8 | 12 |
| July | 23 | 321 | 173 | 78 | 8.1 | - | - | - | 3.08 | 31.2 | 9 |
| July | 30 | 343 | 253 | 80 | 8.9 | 6 | 0.02 | 4.02 | 2.54 | 25.2 | 1 |
| Aug. | 8 | 323 | 276 | 82 | 8.1 | 6 | 0.02 | 4.02 | - | - | - |
| Aug. | 12 | 340 | 201 | 115 | 8.8 | - | 0.03 | 3.95 | 1.22 | M | 5 |
| Aug. | 23 | 243 | M | 47 | M | - | - | - | 4.85 | 40.8 | 1 |
| Sept. | 9 | 259 | 140 | 70 | 7.1 | - | 0.02 | 0.39 | 3.23 | 32.4 | 2 |
| Sept. | 30 | 286 | 195 | 68 | 7.9 | 6 | 0.02 | 2.90 | 3.47 | 33.6 | 4 |
| Nov. | 5 | 345 | 253 | 95 | 11.0 | 16 | 0.10 | 3.75 | 0.25 | 2.4 | 6 |
| Dec. | 3 | 370 | 257 | 104 | 8.6 | - | 0.02 | 3.80 | 0.10 | 1.2 | - |

M - Missing data

APPENDIX 5. Temporal variations in the chemical constituents, 1976.

| | Alkalinity* | Alkalinity* (mg/l) | Calcium Hardness* (mg/l) | Total Hardness* (mg/l) | Total Phosphate (mg/l) | Ortho Phosphate (mg/l) | Organic Phosphate (mg/l) | Meta and poly Phosphate (mg/l) | Nitrate Nitrogen (mg/l) | Organic Nitrogen (mg/l) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | 14 | 123.2 | 143 | 214 | 0.09 | - | - | 0.05 | - | - | 7.53 |
| Feb. | 11 | 125.0 | 142 | 232 | - | - | - | - | 0.21 | - | 7.76 |
| March | 24 | 121.8 | 146 | 240 | 0.08 | - | - | - | - | 0.21 | 7.60 |
| April | 13 | 119.0 | 130 | 236 | 0.11 | - | 0.03 | 0.08 | 0.04 | 0.13 | 7.24 |
| May | 5 | 91.5 | 88 | 128 | 0.11 | - | 0.01 | 0.10 | 0.22 | 0.08 | 7.49 |
| May | 14 | 87.2 | 90 | 136 | 0.25 | 0.19 | 0.10 | 0.06 | 0.13 | 0.17 | 7.58 |
| May | 19 | 89.3 | 98 | 132 | 0.38 | 0.20 | 0.09 | 0.09 | 0.18 | 0.03 | 7.68 |
| May | 26 | 91.5 | 90 | 144 | 0.29 | 0.21 | 0.08 | - | 0.15 | 0.07 | 7.38 |
| June | 4 | 94.3 | 98 | 152 | 0.38 | 0.19 | - | 0.19 | 0.12 | - | 7.61 |
| June | 10 | 94.5 | 96 | 146 | 0.33 | 0.28 | 0.05 | - | 0.16 | 0.04 | 7.64 |
| June | 17 | 84.5 | 78 | 112 | 0.38 | 0.25 | 0.07 | 0.06 | 0.15 | 0.11 | 7,85 |
| June | 25 | 89.0 | 86 | 132 | 0.50 | 0.24 | 0.19 | 0.07 | 0.11 | 0.16 | 7.60 |
| July | 2 | 96.6 | 96 | 142 | 0.39 | 0.29 | 0.04 | 0.06 | 0.08 | 0.04 | 7.66 |
| July | 15 | 95.8 | 108 | 172 | 0.47 | 0.23 | 0.19 | 0.05 | 0.12 | 0.02 | 7.42 |
| July | 23 | 99.0 | 112 | 164 | 0.29 | 0.22 | - | 0.07 | 0.16 | - | 7.51 |
| July | 29 | 94.7 | 104 | 148 | 0.65 | 0.21 | 0.28 | 0.16 | 0.16 | - | 7.44 |
| Aug. | 6 | 90.0 | 84 | 116 | 0.33 | 0.23 | 0.08 | 0.02 | 0.10 | - | 7.49 |
| Aug. | 13 | 96.0 | 100 | 144 | 0.38 | 0.23 | - | 0.15 | 0.07 | - | 7.14 |
| Aug. | 18 | 92.8 | 86 | 116 | 0.40 | 0.26 | 0.05 | 0.09 | 0 10 | 0.11 | 7.14 |
| Sept. | 2 | 100.1 | 106 | 176 | 0.42 | 0.27 | 0.13 | 0.03 | 0.11 | - | 7.64 |
| Sept. | 10 | 105.0 | 120 | 152 | 0.36 | 0.19 | 0.06 | 0.11 | 0.10 | 0.06 | 7.23 |
| Sept. | 30 | 100.0' | 128 | 188 | 0.33 | 0.26 | - | 0.07 | 0.07 | 0.15 | 7.15 |
| Nov. | 17 | 111.2 | 138 | 216 | 0.32 | 0.22 | - | 0.10 | 0.05 | 0.07 | 7.96 |

* as $CaCO_3$

APPENDIX 5. Continued

| | | Conductivity (micromhos) | Total Residue (mg/l) | Sulfate (mg/l) | Chloride (mg/l) | Color | Iron (mg/l) | Silica (mg/l) | Dissolved Oxygen (mg/l) | Dissolved Oxygen (% Sat.) | Turbidity (J.T.U.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | 14 | 365 | 278 | 94 | 8.8 | - | 0.02 | 3.75 | 0.01 | 1.2 | 1.8 |
| Feb. | 11 | 370 | 296 | 105 | 10.1 | - | 0.02 | 3.75 | 3.10 | 31.2 | 0.7 |
| March | 24 | 388 | 332 | 104 | 8.7 | 6 | 0.02 | 3.80 | 0.60 | 5.4 | 0.6 |
| April | 13 | 332 | 276 | 83 | 7.6 | 12 | 0.02 | 3.20 | 1.10 | 10.8 | 0.9 |
| May | 5 | 194 | 151 | 30 | 1.6 | 3 | 0.11 | 1.95 | 7.00 | 66.0 | 1.3 |
| May | 14 | 190 | 157 | 26 | 3.3 | 6 | 0.04 | 2.10 | 7.40 | 70.8 | 1.7 |
| May | 19 | 202 | 183 | 37 | 4.4 | 3 | 0.03 | 2.45 | 6.60 | 63.6 | 1.7 |
| May | 26 | 210 | 119 | 32 | 4.4 | - | 0.02 | 2.30 | 7.40 | 72.0 | 1.4 |
| June | 4 | 218 | 177 | 52 | 5.3 | 6 | 0.06 | 2.70 | 6.30 | 62.4 | 1.5 |
| June | 10 | 219 | 206 | 29 | 4.4 | 6 | 0.01 | 2.25 | 4.50 | 43.2 | 1.1 |
| June | 17 | 192 | 142 | 12 | 2.2 | - | 0.05 | 1.75 | 8.70 | 81.6 | 1.5 |
| June | 25 | 185 | 170 | 16 | 1.6 | - | 0.02 | 1.75 | 9.00 | 85.2 | 0.7 |
| July | 2 | 221 | 166 | 33 | 5.1 | 6 | 0.02 | 2.25 | 6.44 | 62.4 | 1.3 |
| July | 15 | 223 | 350 | 38 | 5.2 | - | 0.02 | 2.35 | 5.73 | 57.6 | 0.5 |
| July | 23 | 300 | 196 | M | 7.9 | 6 | 0.02 | 2.70 | 3.75 | 37.2 | 0.6 |
| July | 29 | 224 | 198 | 55 | 6.1 | - | 0.03 | 2.55 | 5.70 | 56.4 | 1.6 |
| Aug. | 6 | 190 | 185 | 17 | 2.8 | 6 | 0.23 | 2.20 | 9.20 | 88.8 | 4.5 |
| Aug. | 13 | 210 | 201 | 32 | 6.1 | - | 0.02 | 2.40 | 6.04 | 57.6 | 1.0 |
| Aug. | 18 | 185 | 83 | 19 | 3.7 | - | 0.05 | 2.15 | 9.09 | | 2.0 |
| Sept. | 2 | 260 | 199 | 36 | 8.4 | - | 0.02 | 2.85 | 3.30 | 33.6 | 0.8 |
| Sept. | 10 | 311 | 223 | 66 | 10.8 | 6 | 0.02 | 3.05 | 0.21 | 1.8 | 1.2 |
| Sept. | 30 | 380 | 263 | 73 | 10.8 | 3 | 0.02 | 3.60 | 0.70 | 6.6 | 0.7 |
| Nov. | 17 | 355 | 263 | 85 | 13.1 | 16 | 0.02 | 4.10 | 1.10 | 10.2 | 9.7 |

APPENDIX 6. Temporal variations in the physical constituents, 1975.

| | Temperature (°C) | Gauge Height (m) | Discharge ($m^3$/sec.) |
|---|---|---|---|
| June 5 | - | - | 0.333 |
| June 12 | 3.9 | - | 0.304 |
| June 18 | 4.0 | - | 0.286 |
| June 25 | 5.0 | 0.442 | 0.349 |
| July 2 | 1.5 | 0.564 | 0.854 |
| July 9 | 4.5 | 0.433 | 0.328 |
| July 11 | - | 0.424 | 0.288 |
| July 16 | 4.0 | 0.414 | 0.282 |
| July 18 | 5.0 | 0.399 | 0.220 |
| Jyly 20 | - | 0.387 | 0.194 |
| July 22 | 6.7 | 0.375 | 0.176 |
| July 30 | 6.9 | 0.357 | 0.138 |
| Aug. 6 | 6.9 | 0.334 | 0.108 |
| Aug. 12 | - | 0.317 | 0.085 |
| Aug. 23 | 6.2 | 0.405 | 0.208 |
| Aug. 27 | 5.5 | 0.436 | 0.319 |
| Sept. 9 | 6.5 | 0.335 | 0.100 |
| Sept. 30 | 6.5 | 0.335 | 0.106 |
| Nov. 5 | 8.0 | 0.305 | 0.057 |
| Dec. 3 | 7.0 | 0.287 | 0.071 |

APPENDIX 7. Temporal variations in the physical constituents, 1976.

| | Temperature (°C) | Gauge Height (m) | Discharge ($m^3$/sec.) |
|---|---|---|---|
| Jan. 13 | 7.0 | | |
| Feb. 11 | 7.0 | 0.232 | 0.007 |
| March 24 | 7.0 | 0.220 | 0.002* |
| April 13 | 7.0 | 0.293 | 0.041 |
| April 24 | 6.5 | 0.204 | 0.010 |
| May 5 | 4.5 | 0.466 | 0.384 |
| May 14 | 4.8 | 0.415 | 0.246 |
| May 19 | 5.0 | 0.400 | 0.225* |
| May 26 | 4.7 | 0.427 | 0.275 |
| May 28 | 5.3 | 0.430 | 0.299* |
| June 4 | 5.7 | 0.380 | 0.182* |
| June 8 | - | 0.433 | 0.266 |
| June 10 | 5.3 | 0.440 | 0.327* |
| June 13 | 5.6 | 0.440 | 0.327* |
| June 17 | 4.3 | 0.555 | 0.687 |
| June 23 | 4.8 | 0.546 | 0.628 |
| June 25 | 4.3 | 0.500 | 0.514* |
| June 29 | 5.3 | 0.470 | 0.415* |
| July 2 | 5.3 | 0.448 | 0.291 |
| July 6 | 5.3 | 0.427 | 0.239 |
| July 14 | 6.0 | 0.460 | 0.384* |
| July 15 | 6.8 | 0.448 | 0.287 |
| July 23 | 6.6 | 0.390 | 0.145 |
| July 29 | 5.9 | 0.564 | 0.737 |
| Aug. 3 | 5.3 | 0.500 | 0.462 |
| Aug. 5 | 3.9 | 0.616 | 1.198 |
| Aug. 6 | 5.0 | 0.550 | 0.702* |
| Aug. 13 | 4.7 | 0.427 | 0.294 |
| Aug. 16 | - | 0.610 | 0.967* |
| Sept. 2 | 5.1 | 0.378 | 0.162* |
| Sept. 10 | 7.0 | 0.393 | 0.227 |
| Sept. 30 | 7.2 | 0.305 | 0.063 |
| Oct. 14 | 7.6 | 0.300 | 0.054* |
| Nov. 17 | 7.5 | 0.280 | 0.034* |

* Estimated based on rating curve (Fig.

APPENDIX 8. Temporal variations in the percent relative abundance of the Chironomidae taxa at site A, 1975-1976.

| | Diplocladius | Zalutschia | Cricotopus-Orthocladius | Thienemannimyia | Zavrelimyia | Macropelopia | Micropsectra sp.1 | Micropsectra sp.2 | Synorthocladius | Pagastia partica | Polypedilum fallax | Limnophyes | Diamesa sp. 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May 15 | | | | | | | | | | | | | |
| June 6 | - | - | - | - | - | - | - | - | - | 97.8 | - | - | 2.2 |
| July 22 | 1.9 | - | 4.8 | 1.0 | - | - | - | - | - | 92.3 | - | - | - |
| Sept. 9 | - | 2.2 | 74.7 | - | - | - | - | - | - | 23.1 | - | - | - |
| Sept. 30 | - | 1.8 | 81.5 | - | - | - | - | - | - | 53.2 | - | 0.9 | 6.3 |
| Nov. 5 | - | - | 46.6 | - | 3.3 | - | - | - | - | 33.3 | - | 3.3 | - |
| Dec. 3 | | | | | | | | | | | | | |
| Jan. 13 | - | - | 100.0 | - | - | - | - | - | - | - | - | - | - |
| Feb. 11 | 10.3 | - | 29.4 | - | - | - | - | 3.7 | - | 51.4 | - | 2.9 | - |
| April 13 | 66.0 | - | - | - | 4.0 | - | 12.0 | 10.0 | - | - | 4.0 | - | 0.7 |
| May 5 | | | | | | | | | | | | | |
| May 25 | 10.4 | - | 7.5 | - | - | - | 1.5 | 10.4 | - | - | 1.5 | - | 62.7 |
| June 27 | - | - | 6.4 | - | - | - | - | 8.3 | - | 0.9 | - | - | 4.6 |
| July 6 | 3.3 | - | 17.8 | - | - | - | - | - | - | 41.0 | - | 2.2 | 12.2 |
| July 29 | 8.5 | - | 25.6 | 0.8 | - | - | - | - | 2.3 | 35.7 | - | 0.8 | 3.9 |
| Sept. 10 | 1.9 | - | 37.5 | - | - | - | - | - | - | 50.0 | - | - | 4.6 |
| | 14.6 | 2.0 | 48.9 | 0.9 | 3.6 | - | 6.8 | 8.1 | 2.3 | 47.9 | 2.8 | 2.0 | 24.6 |
| | 7.8 | 1.3 | 29.4 | 0.1 | 0.6 | - | 1.0 | 2.5 | 0.2 | 36.8 | 0.4 | 0.8 | 17.5 |

APPENDIX 8. Continued.

| | | *Diamesa* sp. 2 | *Diamesa* sp. 3 | *Diamesa* sp. 4 | *Pseudodiamesa* | *Eukiefferiella* sp. 1 | *Eukiefferiella* sp. 2 | *Paraphaenocladius* | *Potthastia* or *Symposthastia* | *Corynoneura* | *Hydrobaenus* | *Rheocricotopus* | *Heterotrissocladius* | *Phaenopsectra* | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May | 15 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| June | 6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| July | 22 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Sept. | 9 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Sept. | 30 | - | - | - | 6.3 | - | - | - | - | - | - | - | - | - | - |
| Nov. | 5 | - | - | - | - | 3.3 | - | - | 10.0 | - | - | - | - | - | - |
| Dec. | 3 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Jan. | 13 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Feb. | 11 | - | - | - | - | 0.7 | - | - | - | - | - | - | - | - | - |
| April | 13 | - | - | - | - | - | - | - | - | - | - | - | - | 4.0 | - |
| May | 5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| May | 25 | 4.5 | - | - | - | - | - | - | 1.5 | - | - | - | - | - | - |
| June | 27 | - | - | - | 2.8 | 1.9 | - | - | - | - | - | - | - | 75.9 | 0.9 |
| July | 6 | - | - | - | 4.4 | - | - | - | - | - | - | - | - | - | 18.9 |
| July | 29 | - | - | - | - | 0.8 | 0.8 | 0.8 | 20.2 | 0.8 | - | - | - | - | - |
| Sept. | 10 | - | - | - | - | - | - | - | - | - | - | - | - | - | 5.8 |
| | | 4.5 | - | - | 4.5 | 1.7 | 0.8 | 0.8 | 10.6 | 0.8 | - | - | - | 39.9 | 11.2 |
| | | 0.4 | - | - | 1.0 | 0.6 | 0.1 | 0.1 | 2.4 | 0.1 | - | - | - | 6.2 | 2.6 |

APPENDIX 9. Temporal variations in the percent relative abundance of the Chironomidae taxa at site B, 1975-1976.

| | Diplocladius | Zalutschia | Cricotopus-Orthocladius | Thienemannimyia | Zavrelimyia | Macropelopia | Micropsectra sp.1 | Micropsectra sp.2 | Synorthocladius | Pagastia partica | Polypedilum fallax | Limnophyes | Diamesa sp. 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 2 | 18.2 | - | 9.1 | - | - | - | - | 18.2 | - | - | - | - | - |
| April 9 | - | - | - | | | | | | | | | | |
| June | | | | | | | | | | | | | |
| June 25 | - | - | 11.5 | - | - | - | - | - | - | 57.7 | - | - | 7.8 |
| July 22 | - | - | 5.0 | - | - | - | - | - | - | 86.0 | - | - | 1.0 |
| Aug. 12 | 5.7 | - | 44.3 | - | - | - | - | - | - | 45.5 | - | - | 1.1 |
| Sept. 9 | - | - | 57.1 | - | - | - | - | - | - | 33.3 | - | - | 5.2 |
| Sept. 30 | - | - | 18.0 | - | - | - | - | 3.1 | 0.8 | 67.7 | - | - | 2.4 |
| Nov. 5 | 1.7 | - | 21.0 | - | - | - | - | 62.7 | - | 5.0 | - | - | - |
| Jan. 13 | 29.3 | - | 33.4 | - | - | - | - | 11.1 | - | 21.2 | - | - | - |
| Feb. 11 | 7.1 | - | 17.7 | - | 3.5 | - | 1.2 | 28.2 | - | 22.4 | - | - | - |
| March 23 | 21.5 | - | 30.9 | - | - | - | 3.7 | 8.4 | 10.3 | 23.4 | - | - | - |
| April 13 | 32.0 | - | 30.9 | - | 1.0 | - | 6.2 | - | 13.4 | 9.3 | - | - | - |
| May 5 | 4.9 | - | 14.6 | - | - | - | 3.7 | 2.4 | 3.7 | 19.5 | - | 42.7 | 1.2 |
| May 25 | 1.8 | - | 38.1 | - | 1.8 | - | - | 1.8 | 1.8 | 9.1 | - | 1.8 | 32.8 |
| June 27 | - | - | 3.0 | 1.0 | - | - | - | - | - | 72.7 | - | - | 10.2 |
| July 6 | - | - | 10.6 | - | - | - | - | 1.0 | - | 76.0 | - | - | 3.8 |
| Aug. 6 | 11.5 | - | 34.3 | - | - | - | - | 1.0 | - | 51.0 | - | - | - |
| Sept. 10 | 2.2 | - | 21.1 | - | - | - | - | - | 1.1 | 65.6 | - | - | 1.1 |
| | 12.4 | - | 28.0 | 1.0 | 3.8 | - | 3.7 | 13.3 | 5.2 | 41.6 | - | 22.2 | 6.7 |
| | 8.0 | - | 22.4 | 0.1 | 0.9 | - | 0.9 | 7.8 | 1.8 | 39.4 | - | 2.6 | 3.9 |

APPENDIX 9. Continued.

| | | Diamesa sp. 2 | Diamesa sp. 3 | Diamesa sp. 4 | Pseudodiamesa | Eukiefferiella sp. 1 | Eukiefferiella sp. 2 | Paraphaenocladius | Potthastia or Symposthastia | Corynoneura | Hydrobaenus | Rheocricotopus | Heterotrissocladius | Phaenopsectra | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. | 2 | - | - | - | - | - | - | - | - | - | - | - | - | 45.5 | - |
| April | 9 | - | - | - | - | - | - | - | 20.5 | - | - | - | - | 2.6 | 2.6 |
| June | 5 | - | - | - | - | - | - | - | 1.0 | - | - | - | - | 1.0 | 6.0 |
| June | 25 | - | - | - | - | - | - | - | - | - | - | - | - | - | 2.2 |
| July | 22 | - | - | - | - | - | - | - | - | - | - | - | - | - | 4.3 |
| Aug. | 12 | - | - | - | 1.1 | - | - | - | - | - | - | - | - | - | 2.4 |
| Sept. | 9 | - | - | - | - | - | - | - | 4.9 | - | - | - | - | 1.7 | - |
| Sept. | 30 | - | - | - | 1.6 | - | 0.8 | 0.8 | - | - | 0.8 | - | - | - | - |
| Nov. | 5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Jan. | 13 | 1.0 | - | - | - | - | - | - | - | - | - | - | - | - | 3.0 |
| Feb. | 11 | - | - | - | - | - | - | 1.2 | - | - | - | - | - | 18.8 | - |
| March | 23 | - | - | - | - | - | 0.9 | - | - | - | 0.9 | - | - | - | - |
| April | 13 | - | - | - | - | - | 1.0 | - | - | 1.0 | - | - | - | - | 3.1 |
| May | 5 | - | - | - | - | 1.2 | - | - | - | - | - | - | - | - | 1.2 |
| May | 25 | - | - | - | - | 1.8 | - | - | - | 1.8 | - | 1.8 | - | - | - |
| June | 27 | - | - | - | 9.6 | 1.0 | - | - | 11.1 | - | - | - | 1.0 | - | - |
| July | 6 | - | 1.9 | - | - | - | - | - | 4.8 | - | - | - | - | - | - |
| Aug. | 6 | - | - | - | 1.0 | - | - | - | 1.0 | - | - | - | - | - | - |
| Sept. | 10 | - | - | 1.1 | 1.1 | - | - | - | 5.6 | - | - | - | - | - | - |
| | | 1.0 | 1.9 | 1.1 | 2.9 | 1.3 | 0.9 | 1.0 | 7.0 | 1.4 | 0.8 | 1.8 | 1.0 | 13.9 | 3.1 |
| | | 0.1 | 0.1 | 0.1 | 0.8 | 0.2 | 0.2 | 0.1 | 2.9 | 0.2 | - | 0.1 | 0.1 | 4.1 | 1.5 |

APPENDIX 10. Temporal variation in the percent relative abundance of the taxa at site A, 1975-1976.

| | | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera | Trichoptera | Plecoptera |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May | 15 | 0.4 | 0.1 | 11.6 | 10.0 | 45.7 | 26.8 | 1.3 | 2.5 | 1.0 | 0.1 | - | - |
| June | 6 | 23.4 | - | 0.3 | 11.6 | 43.3 | 16.1 | 1.0 | 0.8 | 0.7 | 2.9 | - | - |
| July | 22 | 61.2 | - | 1.0 | 3.0 | 27.6 | 4.6 | 0.5 | - | 0.1 | 1.5 | - | - |
| Sept. | 9 | 19.6 | - | 1.1 | 34.6 | 28.7 | 14.3 | - | 0.3 | 0.6 | 0.6 | 0.1 | - |
| Sept. | 30 | 26.3 | 0.7 | 2.1 | 26.3 | 25.5 | 18.5 | 0.1 | 0.1 | - | 0.3 | - | - |
| Nov. | 5 | 8.6 | 0.5 | - | 46.3 | 30.8 | 11.1 | 0.4 | - | - | 1.1 | - | - |
| Dec. | 3 | 2.1 | - | 16.4 | 38.8 | 33.9 | 8.1 | - | 0.6 | - | - | - | - |
| Jan. | 13 | 1.0 | - | 8.2 | 46.0 | 42.3 | 0.5 | - | 1.9 | - | - | - | - |
| Feb. | 11 | 26.4 | - | 12.8 | 10.3 | 5.4 | 21.6 | 1.6 | 20.7 | 0.3 | - | - | - |
| April | 13 | 8.7 | - | 2.3 | 45.1 | 32.2 | 9.6 | 0.2 | 0.8 | 0.5 | - | - | - |
| May | 5 | 1.6 | 0.1 | 0.2 | 16.6 | 56.0 | 22.0 | 1.9 | 0.6 | 0.1 | 0.1 | - | - |
| May | 25 | 20.9 | 0.6 | 0.2 | 7.2 | 52.7 | 5.5 | 0.4 | 0.3 | 0.4 | 0.7 | - | - |
| June | 27 | 77.1 | 0.2 | 0.7 | 2.2 | 10.3 | 3.0 | 1.3 | 4.1 | 0.2 | 0.3 | - | - |
| July | 6 | 52.1 | 0.1 | 0.5 | 8.9 | 21.7 | 13.4 | 0.1 | 0.1 | 0.4 | 0.6 | 0.1 | - |
| July | 29 | 52.9 | 0.1 | 0.7 | 4.0 | 23.7 | 11.8 | 0.3 | 0.9 | 1.3 | 0.7 | 0.1 | - |
| Sept. | 10 | 43.5 | 0.4 | 0.4 | 20.1 | 20.9 | 8.8 | 0.1 | 0.5 | 3.2 | 1.1 | 0.7 | 0.1 |
| | | 28.6 | 0.3 | 4.3 | 20.7 | 31.3 | 12.2 | 0.7 | 1.0 | 0.7 | 0.8 | 0.2 | 0.1 |
| | | 32.6 | 0.2 | 2.3 | 18.1 | 29.7 | 12.6 | 0.6 | 1.6 | 0.5 | 0.5 | - | - |

APPENDIX 10. Continued.

| | Tipulidae | Muscidae | Empididae | Ceratopogonidae | Psychodidae | Ephydridae | Isopoda | Hydracarina | Tardigrada | Nematoda |
|---|---|---|---|---|---|---|---|---|---|---|
| May 15 | - | - | - | - | - | - | - | - | - | 0.4 |
| June 6 | - | - | - | - | - | - | - | - | - | - |
| July 22 | 0.1 | - | - | - | - | - | - | - | 0.3 | - |
| Sept. 9 | - | - | - | - | - | - | - | - | - | - |
| Sept. 30 | - | - | - | - | - | - | - | - | 0.1 | - |
| Nov. 5 | 0.2 | 0.7 | - | - | - | - | - | - | - | 0.2 |
| Dec. 3 | - | - | - | - | - | - | - | - | - | - |
| Jan. 13 | - | - | - | - | - | - | - | - | - | - |
| Feb. 11 | - | - | - | - | - | - | - | - | - | 0.7 |
| April 13 | - | - | - | - | - | - | - | - | - | 0.6 |
| May 5 | - | - | - | - | - | - | - | - | - | 0.8 |
| May 25 | - | - | - | - | - | - | 0.1 | 0.1 | - | 10.9 |
| June 27 | 0.1 | - | - | 0.2 | - | - | - | - | - | 0.5 |
| July 6 | - | - | - | - | - | - | 0.1 | 0.1 | - | 1.8 |
| July 29 | 0.4 | - | 0.1 | - | 0.4 | - | - | 1.6 | - | 1.2 |
| Sept. 10 | 0.1 | - | - | - | - | - | - | - | - | - |
| | 0.1 | 0.3 | 0.1 | 0.2 | 0.4 | - | 0.1 | 0.4 | 0.2 | 1.7 |
| | - | - | - | - | 0.1 | - | - | 0.2 | - | 1.1 |

APPENDIX 11. Temporal variation in the percent relative abundance of the taxa at site B, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera | Trichoptera | Plecoptera |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 2 | 8.9 | 4.9 | 30.3 | 12.7 | 8.6 | 13.1 | 6.4 | 11.2 | - | - | 0.4 | - |
| April 9 | 0.1 | - | 24.4 | 9.4 | 63.6 | 2.7 | - | - | - | - | - | - |
| June 5 | 1.2 | 9.0 | - | 38.9 | 29.0 | 15.8 | - | 0.1 | 4.8 | 0.4 | 0.1 | - |
| June 25 | 48.5 | 5.2 | - | 10.0 | 24.3 | 7.2 | 0.1 | 0.7 | 0.7 | 1.5 | 0.3 | 0.1 |
| July 22 | 46.8 | 0.3 | - | 1.4 | 40.2 | 10.2 | - | 0.1 | - | 0.9 | 0.1 | - |
| Aug. 12 | 47.2 | 2.9 | - | 16.7 | 20.6 | 10.9 | 0.1 | 0.1 | 0.6 | 0.3 | 0.4 | - |
| Sept. 9 | 48.1 | 33.5 | - | 10.2 | 26.0 | 6.4 | 0.1 | 0.5 | 2.5 | 0.7 | 0.6 | 0.6 |
| Sept. 30 | 41.2 | 8.6 | - | 13.2 | 24.4 | 5.7 | 0.1 | 0.7 | 4.1 | 0.5 | 0.2 | 0.2 |
| Nov. 5 | 34.3 | 0.1 | - | 50.3 | 4.2 | 9.5 | 0.3 | 0.5 | - | 0.1 | 0.3 | - |
| Jan. 13 | 41.7 | 2.8 | - | 37.1 | 11.2 | 5.6 | 0.8 | 0.3 | 0.3 | 0.2 | - | - |
| Feb. 11 | 35.5 | 7.1 | - | 38.8 | 8.9 | 8.7 | 0.4 | 0.4 | - | 0.1 | 0.1 | - |
| March 23 | 60.8 | 1.8 | - | 20.2 | 9.9 | 2.1 | 0.3 | 0.8 | 3.9 | - | 0.1 | - |
| April 13 | 40.1 | 5.1 | - | 21.5 | 8.3 | 12.1 | 0.3 | 1.7 | 9.6 | - | 0.2 | 0.1 |
| May 5 | 11.2 | 5.2 | - | 22.8 | 11.4 | 23.1 | 1.3 | 1.9 | 20.5 | 0.1 | - | 0.1 |
| May 25 | 12.9 | 10.6 | - | 27.5 | 10.3 | 11.7 | 1.3 | 3.6 | 21.8 | 0.3 | - | 0.1 |
| June 27 | 38.8 | 17.0 | - | 7.8 | 11.2 | 5.0 | 0.2 | 1.4 | 15.6 | 1.5 | - | - |
| July 6 | 37.4 | 16.5 | - | 9.0 | 10.0 | 6.5 | - | 0.7 | 16.1 | 1.4 | 0.2 | - |
| Aug. 6 | 40.0 | 11.9 | - | 6.4 | 17.4 | 6.8 | 0.4 | 1.0 | 9.2 | 0.5 | 1.1 | 0.2 |
| Sept. 10 | 55.1 | 10.7 | - | 7.0 | 13.3 | 4.2 | - | 0.1 | 5.2 | 1.2 | 0.3 | 0.1 |
| Sept. 10 | | | | | | | | | | | | |
| | 34.2 | 6.8 | 27.3 | 23.3 | 18.6 | 8.8 | 0.6 | 1.4 | 7.2 | 0.6 | 0.2 | 0.1 |
| | 39.7 | 5.4 | 0.9 | 18.8 | 17.8 | 8.1 | 0.2 | 0.8 | 5.8 | 0.5 | 0.2 | 0.1 |

APPENDIX 11. Continued.

| | | Tipulidae | Muscidae | Empididae | Ceratopogonidae | Psychodidae | Ephydridae | Isopoda | Hydracarina | Tardigrada | Nematoda |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. | 2 | 0.4 | - | - | - | - | - | - | - | - | - |
| April | 9 | - | - | - | - | - | - | - | - | - | - |
| June | 5 | - | - | - | - | - | - | - | - | - | - |
| June | 25 | 0.1 | - | - | - | - | - | - | 0.1 | - | 0.2 |
| July | 22 | - | - | - | - | - | - | - | 0.1 | - | 1.3 |
| Aug. | 12 | - | - | - | - | - | - | - | - | - | - |
| Sept. | 9 | - | 0.1 | - | - | - | - | - | 0.2 | - | 0.1 |
| Sept. | 30 | - | 0.1 | - | - | - | 0.1 | - | 0.1 | 0.1 | 0.4 |
| Nov. | 5 | - | - | - | - | - | - | - | 0.1 | - | 0.9 |
| Jan. | 13 | - | - | - | - | - | - | - | - | - | - |
| Feb. | 11 | - | - | - | - | - | - | - | - | - | - |
| March | 23 | - | - | - | - | - | - | - | - | - | 0.1 |
| April | 13 | - | - | - | - | - | - | - | 0.1 | - | 1.1 |
| May | 5 | 0.1 | - | - | - | - | - | - | 0.3 | - | 2.2 |
| May | 25 | 0.1 | - | - | - | - | - | - | 0.2 | 0.4 | 0.3 |
| June | 27 | - | - | 0.1 | - | - | - | - | 0.4 | - | 0.9 |
| July | 6 | - | - | 0.1 | - | - | - | - | 0.1 | - | 1.8 |
| Aug. | 6 | 0.1 | - | - | - | - | - | - | 0.2 | 0.1 | 4.7 |
| Sept. | 10 | - | 0.1 | - | - | - | - | - | 0.1 | 0.1 | 2.3 |
| | | 0.1 | 0.1 | 0.1 | - | - | 0.1 | - | 0.2 | 0.1 | 1.1 |
| | | - | - | - | - | - | - | - | 0.1 | - | 0.8 |

APPENDIX 12. Temporal variation in the percent relative composition of the biomass of the major taxa at site A, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera | Trichoptera | Plecoptera |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May 15 | 0.5 | 0.7 | 14.9 | 5.8 | 51.8 | 7.6 | 0.1 | 1.3 | 16.5 | 0.7 | - | - |
| June 6 | 19.7 | - | 3.7 | 2.6 | 31.5 | 3.0 | 1.8 | 0.2 | 3.6 | 34.2 | - | - |
| July 22 | 78.7 | - | 0.9 | 0.3 | 7.1 | 0.3 | - | - | 0.2 | 11.2 | - | 0.1 |
| Sept. 9 | 49 | - | 1.5 | 14.1 | 23.4 | 2.2 | - | 0.2 | 3.4 | 0.5 | 4.6 | - |
| Sept. 30 | 33.5 | 22.8 | 28.8 | 3.9 | 6.6 | 2.4 | - | - | - | 0.3 | - | - |
| Nov. 5 | 24.9 | 2.1 | - | 14.3 | 23.8 | 3.2 | - | - | - | 2.6 | - | - |
| Dec. 3 | 4.3 | - | 59.9 | 7.9 | 25.1 | 2.5 | - | 0.2 | - | - | - | - |
| Jan. 13 | 3.3 | - | 35.4 | 13.0 | 47.2 | 2.7 | - | 1.0 | - | - | - | - |
| Feb. 11 | 51.0 | - | 39.1 | 1.9 | 3.4 | 2.7 | 0.6 | 0.4 | 0.9 | - | - | - |
| April 13 | 29.4 | - | 12.2 | 14.8 | 39.5 | 1.9 | 0.4 | 0.6 | - | - | - | - |
| May 5 | 6.8 | 2.4 | 2.0 | 15.1 | 65.6 | 6.2 | 0.7 | 1.1 | - | - | 0.1 | - |
| May 25 | 17.2 | 1.1 | 1.9 | 3.4 | 60.1 | 0.5 | 0.9 | 0.4 | 2.6 | 11.9 | - | - |
| June 27 | 66.7 | 0.2 | 5.0 | 1.7 | 12.5 | 0.8 | 0.6 | 3.8 | 0.4 | 7.3 | - | - |
| July 6 | 82.1 | 0.1 | 0.4 | 2.3 | 9.0 | 1.8 | - | - | 2.2 | 2.1 | 0.1 | - |
| July 29 | 77.7 | 0.1 | 0.9 | 0.7 | 5.3 | 0.9 | - | 0.4 | 4.5 | 8.2 | - | - |
| Sept. 10 | 48.9 | 1.1 | 0.9 | 2.4 | 5.3 | 0.7 | - | 0.3 | 28.4 | 4.4 | 0.5 | 0.3 |
| | 37.1 | 3.4 | 13.8 | 6.5 | 26.1 | 2.4 | 0.7 | 0.7 | 6.3 | 7.6 | 0.9 | 0.1 |
| | 52.3 | 4.2 | 9.7 | 4.5 | 16.4 | 1.8 | 0.2 | 0.6 | 3.8 | 4.8 | 0.4 | - |

APPENDIX 12. Continued.

| | Tipulidae | Muscidae | Empididae |
|---|---|---|---|
| Feb. 2 | 0.3 | - | - |
| April 9 | - | - | - |
| June 5 | - | - | - |
| June 25 | 1.3 | - | - |
| July 22 | - | - | - |
| Aug. 12 | 0.1 | - | - |
| Sept. 9 | 0.2 | 1.9 | 0.1 |
| Sept. 30 | 0.1 | - | 0.2 |
| Nov. 5 | - | - | - |
| | | | |
| Jan. 13 | - | - | - |
| Feb. 11 | - | - | - |
| March 23 | 2.3 | - | - |
| April 13 | 0.3 | - | - |
| May 5 | 0.8 | - | 0.2 |
| May 25 | 8.1 | - | - |
| June 27 | - | - | - |
| July 6 | 0.1 | - | - |
| Aug. 6 | 0.1 | 0.1 | 0.1 |
| Sept. 10 | - | 0.3 | - |
| | 1.0 | 0.7 | 0.1 |
| | 0.8 | 0.1 | - |

APPENDIX 13. Temporal variation in the percent relative biomass composition of the major taxa at site 8, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera | Trichoptera | Plecoptera |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 2 | 12.7 | 26.9 | 51.6 | 2.3 | 1.6 | 1.0 | 1.6 | 1.9 | - | - | 0.3 | - |
| April 9 | 0.1 | - | 11.0 | 1.6 | 87.1 | 0.1 | - | - | - | 0.1 | - | - |
| June 5 | 2.1 | 56.2 | - | 4.6 | 7.9 | 1.3 | - | 0.1 | 16.4 | 11.2 | 0.1 | - |
| June 25 | 43.9 | 33.6 | - | 0.8 | 3.4 | 0.2 | - | 0.4 | 1.3 | 14.9 | - | - |
| July 22 | 57.7 | 5.5 | - | 0.4 | 11.0 | 1.2 | - | - | 0.1 | 4.1 | - | - |
| Aug. 12 | 81.5 | 9.3 | - | 2.0 | 3.0 | 0.5 | - | 0.1 | 1.5 | 3.3 | 0.1 | - |
| Sept. 9 | 46.8 | 36.6 | - | 1.6 | 4.7 | 0.3 | 0.2 | 0.1 | 4.6 | 0.6 | 2.1 | - |
| Sept. 30 | 33.6 | 50.8 | - | 1.2 | 3.1 | 0.2 | 0.2 | - | 9.3 | 0.4 | 0.7 | 0.1 |
| Nov. 5 | 42.0 | 3.8 | - | 39.5 | 7.1 | 4.4 | 0.5 | 1.6 | - | 0.5 | 0.5 | - |
| Jan. 13 | 41.1 | 39.9 | - | 7.2 | 8.6 | 0.8 | 0.2 | 0.1 | 1.6 | 0.2 | 0.2 | - |
| Feb. 11 | 69.8 | 5.3 | - | 5.2 | 7.6 | 1.6 | 0.1 | 2.1 | 7.1 | 0.2 | | - |
| March 23 | 61.3 | 9.7 | - | 5.5 | 13.0 | 0.1 | - | 0.2 | 7.3 | - | 0.7 | - |
| April 13 | 61.1 | 19.9 | - | 0.8 | 0.7 | 0.4 | - | 0.3 | 15.3 | - | 0.8 | 0.2 |
| May 5 | 8.1 | 46.4 | - | 1.5 | 1.2 | 0.7 | 0.3 | 0.1 | 39.5 | 0.4 | 0.6 | - |
| May 25 | 7.9 | 25.9 | - | 2.8 | 1.3 | 0.6 | - | 0.5 | 42.8 | 4.5 | - | 5.6 |
| June 27 | 18.3 | 36.4 | - | 1.2 | 2.0 | 0.2 | - | 0.4 | 25.5 | 15.9 | - | - |
| July 6 | 32.3 | 28.6 | - | 0.6 | 1.3 | 0.1 | - | 0.2 | 20.1 | 16.5 | - | - |
| Aug. 6 | 54.8 | 20.6 | - | 0.5 | 2.5 | 0.2 | 0.1 | 0.3 | 12.7 | 5.9 | 0.8 | 1.1 |
| Sept. 10 | 48.4 | 31.5 | - | - | 2.6 | 0.3 | - | - | 13.6 | 0.3 | 0.8 | 1.3 |
| | 38.1 | 27.0 | 31.3 | 4.2 | 8.9 | 0.7 | 0.3 | 0.5 | 14.4 | 5.8 | 0.6 | 0.7 |
| | 43.7 | 25.0 | 0.7 | 2.2 | 7.9 | 0.4 | 0.1 | 0.3 | 13.4 | 4.6 | 0.5 | 0.5 |

APPENDIX 13. Continued

| | Tipulidae | Muscidae | Empididae |
|---|---|---|---|
| May 15 | - | - | - |
| June 6 | - | - | - |
| July 22 | 1.1 | - | - |
| Sept. 9 | 1.0 | - | - |
| Sept. 30 | 1.1 | 1.2 | - |
| Nov. 5 | 2.3 | 27.0 | - |
| Dec. 3 | - | - | - |
| | | | |
| Jan. 13 | - | - | - |
| Feb. 11 | - | - | - |
| April 13 | 1.4 | - | - |
| May 5 | - | - | - |
| May 25 | - | - | - |
| June 27 | 1.1 | - | - |
| July 6 | - | - | - |
| July 29 | 1.0 | - | 0.3 |
| Sept. 10 | 7.0 | - | - |
| | 2.0 | 9.4 | 0.3 |
| | 0.8 | 0.3 | - |

APPENDIX 14. Temporal variation in the total count of the major taxa at site A, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera | Trichoptera | Plecoptera | Tipulidae |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May 15 | 8 | 2 | 244 | 209 | 959 | 561 | 28 | 52 | 22 | 3 | - | - | - |
| June 6 | 267 | - | 3 | 132 | 493 | 183 | 11 | 9 | 8 | 33 | - | - | - |
| July 22 | 1479 | - | 24 | 72 | 668 | 112 | 11 | 1 | 2 | 36 | - | - | 2 |
| Sept. 9 | 936 | - | 54 | 1648 | 1367 | 683 | 2 | 16 | 28 | 27 | 3 | - | 3 |
| Sept. 30 | 1151 | 30 | 91 | 1151 | 1119 | 812 | 4 | 4 | - | 12 | - | - | 1 |
| Nov. 5 | 39 | 2 | - | 209 | 139 | 50 | 2 | - | - | 5 | - | - | 1 |
| Dec. 3 | 16 | - | 126 | 298 | 260 | 62 | - | 5 | - | - | - | - | - |
| Jan. 13 | 8 | - | 66 | 370 | 340 | 4 | - | 16 | - | - | - | - | - |
| Feb. 11 | 302 | - | 147 | 118 | 62 | 247 | 19 | 237 | 3 | 2 | - | - | 1 |
| April 13 | 270 | - | 72 | 1402 | 1001 | 297 | 7 | 24 | 16 | - | - | - | - |
| May 5 | 51 | 3 | 7 | 518 | 1749 | 689 | 60 | 19 | 2 | 2 | 1 | - | - |
| May 25 | 435 | 12 | 4 | 150 | 1097 | 114 | 9 | 6 | 8 | 14 | - | - | - |
| June 27 | 3433 | 9 | 30 | 99 | 458 | 136 | 60 | 182 | 8 | 14 | - | - | 3 |
| July 6 | 1577 | 3 | 15 | 270 | 657 | 407 | 4 | 2 | 12 | 18 | 2 | - | - |
| July 29 | 2065 | 2 | 27 | 155 | 925 | 461 | 11 | 34 | 50 | 29 | 2 | - | 16 |
| Sept. 10 | 588 | 6 | 5 | 275 | 283 | 119 | 1 | 7 | 43 | 15 | 9 | 1 | 1 |
| | 12725 | 69 | 915 | 7076 | 11577 | 4937 | 229 | 614 | 202 | 210 | 17 | 1 | 28 |

APPENDIX 14. Continued.

| | | Muscidae | Empididae | Ceratopogonidae | Psychodidae | Ephydridae | Isopoda | Hydracarina | Tardigrada | Nematoda |
|---|---|---|---|---|---|---|---|---|---|---|
| May | 15 | - | - | - | - | - | 1 | - | - | 8 |
| June | 6 | - | - | - | - | - | - | - | - | - |
| July | 22 | - | - | - | - | - | - | - | 8 | 1 |
| Sept. | 9 | - | - | - | - | - | - | - | - | - |
| Sept. | 30 | 4 | - | - | - | - | - | - | 2 | - |
| Nov. | 5 | 3 | - | - | - | - | - | - | - | 1 |
| Dec. | 3 | - | - | - | - | - | - | - | - | - |
| Jan. | 13 | - | - | - | - | - | - | - | - | - |
| Feb. | 11 | - | - | - | - | - | - | - | - | 8 |
| April | 13 | - | - | - | - | - | - | - | - | 20 |
| May | 5 | - | - | - | - | - | 1 | - | - | 24 |
| May | 25 | - | - | - | - | - | 1 | - | - | 228 |
| June | 27 | - | - | 7 | - | - | - | 2 | - | 24 |
| July | 6 | - | - | - | - | - | 2 | 1 | - | 54 |
| July | 29 | 1 | 5 | - | 15 | - | - | 2 | - | 46 |
| Sept. | 10 | - | - | - | - | - | - | 63 | - | - |
| | | 8 | 5 | 7 | 15 | - | 5 | 68 | 10 | 414 |

APPENDIX 15. Temporal variation in the total count of the major taxa at site B, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera | Trichoptera |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 2 | 24 | 13 | 81 | 34 | 23 | 35 | 17 | 30 | - | - | 1 |
| April 9 | 3 | - | 831 | 319 | 2159 | 100 | - | - | - | 1 | - |
| June 5 | 34 | 246 | - | 1060 | 791 | 432 | - | 3 | 131 | 12 | - |
| June 25 | 759 | 82 | - | 156 | 380 | 112 | 2 | 11 | 12 | 24 | 3 |
| July 22 | 2902 | 16 | - | 86 | 2491 | 632 | 1 | 3 | 1 | 58 | 5 |
| Aug. 12 | 5952 | 363 | - | 2106 | 2594 | 1374 | 16 | 9 | 77 | 42 | 52 |
| Sept. 9 | 2929 | 212 | - | 618 | 1585 | 391 | 5 | 33 | 154 | 41 | 37 |
| Sept. 30 | 3435 | 712 | - | 1098 | 2032 | 474 | 6 | 56 | 341 | 42 | 14 |
| Nov. 5 | 942 | 4 | - | 1380 | 124 | 260 | 8 | 12 | - | 2 | 7 |
| Jan. 13 | 2818 | 186 | - | 2507 | 756 | 381 | 51 | 20 | 22 | 14 | 3 |
| Feb. 11 | 2610 | 522 | - | 2859 | 653 | 640 | 30 | 27 | 2 | 4 | 4 |
| March 23 | 6256 | 186 | - | 2078 | 1021 | 212 | 29 | 78 | 405 | - | 10 |
| April 13 | 3271 | 417 | - | 1752 | 673 | 984 | 20 | 141 | 783 | 3 | 12 |
| May 5 | 426 | 197 | - | 868 | 434 | 880 | 49 | 74 | 782 | 4 | 1 |
| May 25 | 680 | 554 | - | 1446 | 541 | 616 | 8 | 187 | 1147 | 15 | - |
| June 27 | 1987 | 872 | - | 400 | 576 | 254 | 8 | 72 | 800 | 79 | 1 |
| July 6 | 1828 | 806 | - | 440 | 488 | 319 | 2 | 36 | 785 | 70 | 10 |
| Aug. 6 | 1467 | 436 | - | 235 | 637 | 250 | 14 | 38 | 337 | 17 | 39 |
| Sept. 10 | 3703 | 720 | - | 472 | 895 | 279 | 2 | 6 | 353 | 81 | 23 |
| | 42026 | 5672 | 912 | 19914 | 18853 | 8625 | 268 | 836 | 6132 | 505 | 226 |

APPENDIX 15. Continued.

| | Plecoptera | Tipulidae | Muscidae | Empididae | Ceratopogonidae | Psychodidae | Ephydridae | Isopoda | Hydracarina | Tardigrada | Nematoda |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 2 | - | 1 | - | - | - | - | - | - | - | - | 8 |
| April 9 | - | - | - | - | - | - | - | - | - | - | - |
| June 5 | 1 | - | - | - | - | - | - | 1 | 4 | - | 6 |
| June 25 | 1 | 1 | - | - | - | - | - | - | 1 | - | 20 |
| July 22 | 1 | - | - | 1 | - | - | - | - | - | - | - |
| Aug. 12 | 5 | 1 | - | - | - | - | - | - | - | - | 17 |
| Sept. 9 | 36 | 1 | 8 | 2 | - | - | - | - | 10 | - | 24 |
| Sept. 30 | 19 | 1 | 12 | - | - | - | - | - | 12 | 4 | 73 |
| Nov. 5 | - | - | - | - | - | - | 1 | - | 3 | - | 1 |
| Jan. 13 | - | 1 | - | - | - | - | - | - | - | - | 1 |
| Feb. 11 | - | - | 1 | - | - | - | - | - | - | - | - |
| March 23 | - | 1 | - | - | - | - | - | - | 4 | 1 | 9 |
| April 13 | 5 | 3 | - | - | - | - | - | - | 7 | - | 87 |
| May 5 | 3 | 4 | - | 1 | - | - | - | - | 10 | - | 82 |
| May 25 | 6 | 4 | - | - | - | - | - | 6 | 8 | 18 | 15 |
| June 27 | 2 | 1 | - | 5 | - | - | - | 1 | 19 | 2 | 44 |
| July 6 | 2 | 1 | - | 5 | - | - | - | - | 5 | - | 88 |
| Aug. 6 | 7 | 3 | 1 | - | 1 | - | - | 1 | 7 | 2 | 172 |
| Sept. 10 | 8 | - | 7 | 3 | 1 | - | - | - | 5 | 4 | 156 |
| | 96 | 24 | 29 | 17 | 2 | - | 2 | 9 | 95 | 31 | 803 |

APPENDIX 16. Temporal variation in the biomass (mg) of the major taxa at site A, 1975-1976.

| | | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpactocoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera |
|---|---|---|---|---|---|---|---|---|---|---|---|
| May | 15 | 0.3 | 0.4 | 9.0 | 3.5 | 31.1 | 4.6 | 0.1 | 0.8 | 9.9 | 0.4 |
| June | 6 | 10.0 | - | 1.9 | 1.3 | 16.0 | 1.5 | 0.9 | 0.1 | 1.7 | 17.4 |
| July | 22 | 186.4 | - | 2.2 | 0.7 | 16.9 | 0.7 | 1.0 | - | 0.4 | 26.5 |
| Sept. | 9 | 79.5 | - | 2.4 | 22.3 | 38.0 | 3.6 | - | 0.3 | 5.6 | 0.8 |
| Sept. | 30 | 140.0 | 96.0 | 121.3 | 16.4 | 27.6 | 10.2 | - | 0.1 | - | 1.3 |
| Nov. | 5 | 4.7 | 0.4 | - | 2.7 | 4.5 | 0.6 | - | - | - | 0.5 |
| Dec. | 3 | 1.9 | - | 26.5 | 3.5 | 11.1 | 1.1 | - | 0.1 | - | - |
| Jan. | 13 | 1.0 | - | 10.6 | 3.9 | 14.1 | - | - | 0.3 | - | - |
| Feb. | 11 | 34.4 | - | 26.4 | 1.3 | 2.3 | 1.8 | 0.4 | 0.3 | 0.6 | - |
| April | 13 | 40.6 | - | 16.9 | 20.4 | 54.6 | 2.6 | 0.5 | 0.8 | - | - |
| May | 5 | 6.1 | 2.1 | 1.8 | 13.4 | 58.4 | 5.5 | 0.6 | 1.0 | - | - |
| May | 25 | 13.7 | 0.9 | 1.5 | 2.7 | 47.9 | 0.4 | 0.7 | 0.3 | 2.1 | 9.5 |
| June | 27 | 80.5 | 0.2 | 6.0 | 2.1 | 15.1 | 0.9 | 0.7 | 4.6 | 0.5 | 8.8 |
| July | 6 | 224.3 | 0.2 | 1.1 | 6.3 | 24.5 | 4.8 | 0.1 | 0.1 | 5.9 | 5.7 |
| July | 29 | 362.1 | 0.4 | 4.0 | 3.3 | 24.5 | 4.2 | 0.3 | 1.9 | 20.8 | 38.2 |
| Sept. | 10 | 74.3 | 1.6 | 1.3 | 3.6 | 8.0 | 1.1 | - | 0.4 | 43.1 | 6.7 |
| | | 1260.7 | 102.2 | 232.9 | 107.9 | 394.9 | 43.6 | 4.0 | 15.1 | 90.6 | 115.8 |

APPENDIX 16. Continued.

| | Trichoptera | Plecoptera | Tipulidae | Muscidae | Empididae |
|---|---|---|---|---|---|
| May 15 | - | - | - | - | - |
| June 6 | - | - | - | - | - |
| July 22 | 0.1 | 0.3 | 2.5 | - | - |
| Sept. 9 | 7.5 | - | 1.6 | - | - |
| Nov. 5 | - | 0.1 | 4.8 | 1.8 | - |
| Dec. 3 | - | - | 0.4 | 5.1 | - |
| Jan. 13 | - | - | - | - | - |
| Feb. 11 | - | - | - | - | - |
| April 13 | - | - | 1.9 | - | - |
| May 5 | 0.1 | - | - | - | - |
| May 25 | - | - | - | - | - |
| June 27 | - | - | 1.3 | - | - |
| July 6 | 0.2 | - | - | - | - |
| July 29 | 0.2 | - | 4.5 | 0.2 | 1.3 |
| Sept. 10 | 0.7 | 0.4 | 10.6 | - | - |
| | 8.8 | 0.8 | 27.6 | 7.1 | 1.3 |

APPENDIX 17. Temporal variation in the biomass (mg) of the major taxa at site B, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera |
|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 2 | 3.9 | 8.3 | 15.9 | 0.7 | 0.5 | 0.3 | 0.5 | 0.6 | - | - |
| April 9 | 0.5 | - | 71.1 | 10.6 | 563.5 | 0.9 | - | - | - | 0.3 |
| June 5 | 5.4 | 142.5 | - | 11.7 | 20.0 | 3.2 | - | 0.2 | 41.6 | 28.5 |
| June 25 | 124.0 | 95.1 | - | 2.3 | 9.5 | 0.7 | - | 1.1 | 3.8 | 42.3 |
| July 22 | 196.1 | 18.6 | - | 1.3 | 37.5 | 4.0 | - | - | 0.8 | 81.8 |
| Aug. 12 | 1185.5 | 134.7 | - | 29.2 | 44.3 | 6.7 | 0.6 | 0.9 | 21.6 | 48.7 |
| Sept. 9 | 343.8 | 269.2 | - | 12.2 | 34.8 | 2.1 | 1.5 | 1.1 | 33.7 | 4.3 |
| Sept. 30 | 381.9 | 578.7 | - | 14.2 | 35.3 | 2.9 | - | 2.5 | 105.9 | 4.8 |
| Nov. 5 | 15.4 | 1.4 | - | 14.5 | 2.6 | 1.6 | 0.2 | 0.6 | - | 0.2 |
| Jan. 13 | 130.8 | 127.0 | - | 22.9 | 27.5 | 2.7 | 0.7 | 0.3 | 5.1 | 0.5 |
| Feb. 11 | 328.9 | 24.8 | - | 29.4 | 35.6 | 7.6 | 0.5 | 10.1 | 0.4 | 0.8 |
| March 23 | 864.1 | 136.4 | - | 77.1 | 183.4 | 1.1 | 0.3 | 3.1 | 102.8 | - |
| April 13 | 1038.5 | 338.6 | - | 14.1 | 11.2 | 7.1 | 0.6 | 5.4 | 259.6 | 0.6 |
| May 5 | 58.1 | 332.1 | - | 10.8 | 8.9 | 5.3 | 2.1 | 0.8 | 283.1 | 3.2 |
| May 25 | 57.1 | 187.1 | - | 20.4 | 9.3 | 4.1 | 0.2 | 3.5 | 309.9 | 32.7 |
| June 27 | 169.4 | 336.6 | - | 11.4 | 18.6 | 1.4 | 0.3 | 4.0 | 236.0 | 147.2 |
| July 6 | 390.1 | 345.4 | - | 7.0 | 15.8 | 1.7 | - | 2.0 | 243.2 | 198.7 |
| Aug. 6 | 428.1 | 161.2 | - | 3.6 | 19.8 | 1.8 | 0.6 | 2.1 | 99.2 | 46.0 |
| Sept. 10 | 361.2 | 234.9 | - | 7.2 | 19.8 | 2.3 | - | 0.3 | 101.5 | 2.8 |
| | 6082.8 | 3472.6 | 87.0 | 300.5 | 1097.9 | 57.5 | 8.0 | 38.6 | 1858.9 | 643.4 |
| | 320.1 | 182.7 | 4.6 | | | | | | | |

APPENDIX 17. Continued.

| | Trichoptera | Plecoptera | Tipulidae | Muscidae | Empididae |
|---|---|---|---|---|---|
| Feb. 2 | 0.1 | - | 0.1 | - | - |
| April 9 | - | - | - | - | - |
| June 5 | - | 0.1 | - | - | - |
| June 25 | 0.2 | 0.1 | 3.7 | - | - |
| July 22 | 0.4 | 0.1 | - | - | 0.4 |
| Aug. 12 | 2.2 | 0.2 | 0.9 | - | - |
| Sept. 9 | 15.8 | - | 1.8 | 14.3 | 2.1 |
| Sept. 30 | 7.8 | 1.3 | 0.9 | - | - |
| Nov. 5 | 0.2 | - | - | - | - |
| | | | | | |
| Jan. 13 | 0.8 | - | 0.1 | - | - |
| Feb. 11 | - | - | 00.1 | - | - |
| March 23 | 9.3 | - | 33.0 | - | - |
| April 13 | 13.8 | 3.8 | 5.9 | - | - |
| May 5 | 4.4 | 0.3 | 5.7 | - | 1.1 |
| May 25 | - | 40.4 | 58.7 | - | - |
| June 27 | 0.1 | 0.4 | 0.1 | - | 0.3 |
| July 6 | 0.1 | 0.4 | 1.6 | - | 0.5 |
| Aug. 6 | 6.0 | 8.5 | 0.8 | 0.6 | 0.8 |
| Sept. 10 | 6.2 | 9.7 | - | 2.1 | 0.2 |
| | 67.0 | 65.4 | 113.4 | 17.0 | 5.4 |

APPENDIX 18. Temporal variation in the mean individual weight of the major taxa at site A, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Harpacticoida | Enchytraeidae | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera |
|---|---|---|---|---|---|---|---|---|---|---|
| May 15 | 0.038 | 0.200 | 0.037 | 0.017 | 0.008 | 0.032 | 0.002 | 0.015 | 0.45 | 0.13 |
| June 6 | 0.037 | - | 0.633 | 0.010 | 0.008 | 0.032 | 0.080 | 0.011 | 0.21 | 0.53 |
| July 22 | 0.126 | - | 0.092 | 0.010 | 0.006 | 0.025 | 0.091 | 0.020 | 0.20 | 0.74 |
| Sept. 9 | 0.085 | - | 0.044 | 0.014 | 0.005 | 0.028 | ? | 0.019 | 0.20 | 0.03 |
| Sept. 30 | 0.122 | 3.200 | 1.333 | 0.014 | 0.013 | 0.025 | ? | 0.025 | - | 0.11 |
| Nov. 5 | 0.121 | 0.200 | - | 0.013 | 0.012 | 0.032 | - | - | - | 0.10 |
| Dec. 3 | 0.119 | - | 0.210 | 0.012 | 0.012 | 0.043 | - | 0.020 | - | - |
| Jan. 13 | 0.125 | - | 0.161 | 0.011 | - | 0.041 | ? | 0.019 | - | - |
| Feb. 11 | 0.114 | - | 0.180 | 0.011 | 0.007 | 0.037 | 0.021 | 0.001 | 0.20 | - |
| April 13 | 0.150 | - | 0.235 | 0.015 | 0.009 | 0.055 | 0.071 | 0.033 | ? | - |
| May 5 | 0.120 | 0.700 | 0.450 | 0.026 | 0.008 | 0.033 | 0.010 | 0.053 | ? | - |
| May 25 | 0.031 | 0.075 | 0.375 | 0.018 | 0.004 | 0.044 | 0.111 | 0.050 | 0.26 | 0.68 |
| June 27 | 0.023 | 0.022 | 0.200 | 0.021 | 0.007 | 0.033 | 0.012 | 0.025 | 0.06 | 0.63 |
| July 6 | 0.142 | 0.067 | 0.073 | 0.023 | 0.012 | 0.037 | 0.025 | 0.050 | 0.69 | 0.32 |
| July 29 | 0.175 | 0.200 | 0.148 | 0.021 | 0.009 | 0.027 | 0.027 | 0.056 | 0.41 | 0.32 |
| Sept. 10 | 0.126 | 0.267 | 0.260 | 0.013 | 0.009 | 0.028 | ? | 0.057 | 1.00 | 0.45 |
| | 0.103 | 0.548 | 0.295 | 0.016 | 0.009 | 0.034 | 0.019 | 0.025 | 0.35 | 0.46 |

APPENDIX 18. Continued.

| | Trichoptera | Plecoptera | Tipulidae | Muscidae | Empididae |
|---|---|---|---|---|---|
| May 15 | - | - | - | - | - |
| June 6 | - | - | - | - | - |
| July 22 | ? | - | 1.25 | - | - |
| Sept. 9 | 2.50 | - | 0.53 | - | - |
| Sept. 30 | - | - | 4.80 | 0.45 | - |
| Nov. 5 | - | - | 0.40 | 1.70 | - |
| Dec. 3 | - | - | - | - | - |
| Jan. 13 | - | - | - | - | - |
| Feb. 11 | - | - | - | - | - |
| April 13 | - | - | 1.90 | - | - |
| May 5 | 0.08 | - | - | - | - |
| May 25 | - | - | - | - | - |
| June 27 | - | - | 1.30 | - | - |
| July 6 | 0.10 | - | - | - | - |
| July 29 | 0.10 | - | 0.28 | 0.20 | 0.30 |
| Sept. 10 | 0.08 | 0.40 | 10.60 | - | - |
| | 0.57 | 0.40 | 2.63 | 0.78 | 0.30 |

APPENDIX 19. Temporal variation in the mean individual weight of the major taxa at site B, 1975-1976.

| | Chironomidae | Lumbriculidae | Tubificidae | Naididae | Enchytraeidae | Harpacticoida | Cyclopoida | Ostracoda | Tricladida | Ephemeroptera |
|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 2 | 0.162 | 0.638 | 0.196 | 0.021 | 0.022 | 0.009 | 0.059 | 0.020 | - | - |
| April 9 | 0.167 | - | 0.086 | 0.033 | 0.026 | 0.009 | - | - | - | 0.30 |
| June 5 | 0.159 | 0.579 | - | 0.011 | 0.025 | 0.008 | - | 0.067 | 0.318 | 2.38 |
| June 25 | 0.163 | 1.160 | - | 0.015 | 0.025 | 0.006 | ? | 0.100 | 0.317 | 1.76 |
| July 22 | 0.068 | 1.160 | - | 0.015 | 0.015 | 0.006 | ? | - | 0.300 | 1.41 |
| Aug. 12 | 0.199 | 0.371 | - | 0.014 | 0.017 | 0.005 | 0.038 | 0.100 | 0.280 | 1.16 |
| Sept. 9 | 0.117 | 1.270 | - | 0.020 | 0.022 | 0.005 | 0.030 | 0.033 | 0.219 | 0.10 |
| Sept. 30 | 0.111 | 0.813 | - | 0.013 | 0.017 | 0.006 | ? | 0.045 | 0.311 | 0.11 |
| Nov. 5 | 0.016 | 0.350 | - | 0.011 | 0.021 | 0.006 | 0.025 | 0.050 | - | 0.10 |
| Jan. 13 | 0.046 | 0.733 | - | 0.009 | 0.036 | 0.007 | 0.014 | 0.015 | 0.232 | 0.04 |
| Feb. 11 | 0.126 | 0.048 | - | 0.010 | 0.055 | 0.012 | 0.017 | 0.037 | 0.198 | 0.20 |
| March 23 | 0.138 | 0.682 | - | 0.037 | 0.018 | 0.005 | 0.010 | 0.040 | 0.254 | - |
| April 13 | 0.317 | 0.813 | - | 0.008 | 0.017 | 0.007 | 0.030 | 0.038 | 0.332 | 0.20 |
| May 5 | 0.136 | 1.686 | - | 0.012 | 0.021 | 0.006 | 0.043 | 0.011 | 0.362 | 0.80 |
| May 25 | 0.084 | 0.338 | - | 0.014 | 0.017 | 0.007 | 0.025 | 0.019 | 0.270 | 2.18 |
| June 27 | 0.085 | 0.386 | - | 0.028 | 0.032 | 0.006 | 0.038 | 0.056 | 0.295 | 1.86 |
| July 6 | 0.213 | 0.429 | - | 0.016 | 0.032 | 0.005 | ? | 0.056 | 0.310 | 2.84 |
| Aug. 6 | 0.292 | 0.370 | - | 0.015 | 0.031 | 0.007 | 0.043 | 0.055 | 0.294 | 2.71 |
| Sept. 10 | 0.098 | 0.326 | - | 0.015 | 0.022 | 0.008 | ? | 0.050 | 0.288 | 0.04 |
| | 0.142 | 0.759 | 0.141 | 0.017 | 0.027 | 0.007 | 0.020 | 0.066 | 0.286 | 1.14 |

APPENDIX 19. Continued.

| | Trichoptera | Plecoptera | Tipulidae | Muscidae | Empididae |
|---|---|---|---|---|---|
| Feb. 2 | 0.10 | - | 0.10 | - | - |
| April 9 | | - | - | - | - |
| June 5 | - | 0.01 | - | - | - |
| June 25 | 0.07 | 0.01 | 3.70 | - | - |
| July 22 | 0.08 | 0.01 | - | - | 0.40 |
| Aug. 12 | 0.04 | 0.05 | 0.90 | - | 1.05 |
| Sept. 9 | 0.43 | - | 1.80 | 1.79 | - |
| Sept. 30 | 0.56 | 0.07 | 0.90 | - | - |
| Nov. 5 | 0.03 | - | - | - | - |
| | | | | | |
| Jan. 13 | 0.27 | - | 0.10 | - | - |
| Feb. 11 | ? | - | 0.10 | - | - |
| March 23 | 0.93 | - | 33.00 | - | - |
| April 13 | 1.15 | 0.76 | 1.97 | - | - |
| May 5 | 4.40 | 0.10 | 1,42 | - | 1.10 |
| May 25 | - | 6.73 | 14.68 | - | - |
| June 27 | 0.10 | 0.20 | 0.10 | - | 0.06 |
| July 6 | 0.01 | 0.20 | 1.60 | - | 0.10 |
| Aug. 6 | 0.15 | 1.21 | 0.27 | 0.60 | - |
| Sept. 10 | 0.27 | 1.21 | - | 0.30 | 0.07 |
| | 0.61 | 0.89 | 4.32 | 0.90 | 0.46 |